REVISED EDITION

ELEMENTS OF NATURAL PHILOSOPHY

·AVERY·

ELEMENTS

OF

NATURAL PHILOSOPHY.

A TEXT-BOOK

FOR HIGH SCHOOLS AND ACADEMIES.

BY

ELROY M. AVERY, PH.D.,

AUTHOR OF A SERIES OF PHYSICAL SCIENCE TEXT-BOOKS.

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TO THE TEACHER.

IN this book will be found an unusual number of problems. It is not intended that each member of each class shall work all of the problems. It is hoped that they are sufficiently numerous and varied to enable you to select what you need for your particular class. No author can make a comfortable Procrustean bedstead.

You would do well to secure, in the fall of the year, a supply of the pith of elder or sunflower stalk, and several full-blown thistle-heads, that they may be well dried and ready for experiments in electricity during the dry, cold weather of winter.

The author would be glad to receive any suggestions from any of his fellow-teachers who may use this book, or to answer any inquiries concerning the study or apparatus.

Most of the apparatus mentioned in this book may be obtained from JAMES W. QUEEN & Co., Philadelphia.

The author has prepared a Teacher's Hand-Book to accompany this volume, with answers to the problems, and much additional matter of interest to teachers of Natural Philosophy.

TO THE PUPIL.

RECENT careful and extended examination shows that diseases of the eye, such as near-sight, are lamentably frequent among school-children. Your eyesight is worth more to you than any information you are likely to gain from this book, however valuable that may be. You are therefore *earnestly cautioned:*

1. To be sure, in studying this or any other book, that you have sufficient light.

2. That you do not allow direct rays of light to fall upon your eyes, and that you avoid the angle of reflection.

3. That you avoid a stooping position and a forward inclination of the head. Do not read with the book in your lap. The distance of the eye from the page should be not less than twelve inches (30 cm.) nor more than eighteen inches (45 cm.) *Hold the book up.*

4. That you sit erect when you write. The light should be received over your left shoulder.

5. Especially, that you avoid, as much as possible, books and papers poorly printed or printed in small type.

6. That you cleanse the eyes with pure soft water morning and night, and avoid overtaxing them *in any way.*

- KNOWLEDGE.
  - UNCLASSIFIED.
  - CLASSIFIED, OR COÖRDINATED.
    - OF SPACE AND TIME..........
      - MATHEMATICS.
    - OF MATTER AND ENERGY.....
      - GEOGRAPHY.
      - ASTRONOMY.
      - PHYSICS.
      - CHEMISTRY.
    - OF MATTER, ENERGY, AND LIFE
      - BOTANY.
      - ZOOLOGY.
      - ANATOMY.
      - PHYSIOLOGY.
      - ETC., ETC.
    - OF MIND........................
      - PSYCHOLOGY.
      - LOGIC.
      - PHILOLOGY.
    - OF SOCIETY......................
      - HISTORY.
      - POLITICAL ECONOMY.
      - SOCIOLOGY.
      - ETC.

CHAPTER I.

THE DOMAIN OF PHYSICS.—THE PROPERTIES OF MATTER.—THE THREE CONDITIONS OF MATTER.

SECTION I.

THE DOMAIN OF PHYSICS, OR NATURAL PHILOSOPHY.

Introductory.—On the page opposite, you have an outline map of the wide realm of human knowledge. As from a mountain top, you look upon the plain below, and clearly see the position of each province, and its relation to its neighbors. Through some of these provinces you may have passed, and with them have become more or less familiar. From the whole number we now select one that promises enough of interest and profit to justify the time and effort of careful study. Not satisfied with the cursory glance, we seek more definite information. For this, we must leave the peak and enter the plain; for though distance may lend an enchantment, it also begets a dimness fatal to our purpose.

1. What is Science?—*Science is classified knowledge.*

A person may have lived for years among plants, have acquired a vast store of information concerning them, know that this one grows only in wet ground, that another is valuable for such and such an end, and that a third has certain form, size, and color. This general information may be valuable, but it is only when the facts are classified, and the plants grouped into their respective orders, genera and species, that the knowledge becomes entitled to the name of botany, *a science.*

2. What is Matter?—*Matter is anything that occupies space or "takes up room."*

There are many realities that are not forms of matter. Mind, truth, and hope do not occupy space; the earth and the rain-drop do.

3. Divisions of Matter.—*Matter may be considered as existing in masses, molecules, and atoms.*

A clear apprehension of the meaning of these terms is essential to a full understanding of the definition of Physics as well as of much else that follows.

4. What is a Mass?—*A mass is any quantity of matter that is composed of molecules.*

The word molar is used to describe such a collection of molecules.

(*a.*) The term mass also has reference to real quantity as distinguished from apparent quantity or size. A sponge may be compressed so as to seem much smaller than at first, but all of the sponge is still there. Its density is changed; its quantity or *mass* remains the same. This double use of the word is unfortunate, but the meaning in any given case may be easily inferred from the connection.

(*b.*) The quantity of matter constituting a mass is not necessarily great. A drop of water may contain a million animalcules; each animalcule is a mass as truly as the greatest monster of the land or sea. The dewdrop and the ocean, clusters of grapes and clusters of stars, are equally masses of matter.

5. What is a Molecule?—*A molecule is the smallest quantity of matter that can exist by itself.* It is the physical unit of matter and can be divided only by chemical means.

(*a.*) We know that a drop of water may be divided into several parts, and each of these into several others, each part still being water. The subdivision may be carried on until we reach a limit fixed by the grossness of our instruments and vision; each particle still is water. Even now, imagination may carry forward the work of subdivision until at last we reach a limit beyond which we cannot go without destroying the identity of the substance. In other words, we have a quantity of water so small that if we divide it again it will cease to be water; it will be something else. This smallest quantity of matter that can exist by itself and retain its identity is called a molecule. The word *molecule* means *a little mass.* (See Avery's Chemistry, § 4.)

(*b.*) The smallest interval that can be distinctly seen with the microscope is about $\frac{1}{80000}$ inch. It has been calculated that about 2000 liquid water molecules might be placed in a row within such an interval. In other words, an aggregation of 8,000,000,000 water molecules is barely visible to the best modern microscopes.

6. What is an Atom?—*An atom is the smallest quantity of matter that can enter into combination.* It is the chemical unit of matter and is considered indivisible.

In nearly every case an atom is a part of a molecule.

(*a.*) If a molecule of water be divided, it will cease to be water at all, but will yield two atoms of hydrogen and one of oxygen. The molecule of common salt consists of one atom of sodium and one of chlorine. Some molecules are very complex. The common sugar molecule contains forty-five atoms.

(*b.*) Atoms make molecules; molecules make masses. Of the *absolute* size and weight of atoms and molecules little is known; of their *relative* size and weight much is known, and forms an important part of the science of chemistry.

7. Forms of Attraction.—Each of these three divisions of matter has its own form of attraction:

Molar attraction is called gravitation.

Molecular attraction is called cohesion or adhesion.

Atomic attraction is called chemical affinity (chemism).

8. Forms of Motion.—Each of these three divisions of matter has its own form of motion :

Molar motion, or visible mechanical motion, is called by different names according to the nature of the substance in motion; *e. g.*, the flow of a river or the vibrations of a pendulum.

Molecular motion, called heat, light, electricity, or magnetism.

Atomic motion. (Purely theoretical as far as known.)

9. Physical Science.—*Physical science comprises Physics and Chemistry.*

The first of these deals with masses and molecules; the second with atoms and combinations of atoms.

10. What is a Physical Change?—*A physical change is one that does not change the identity of the molecule.*

(*a.*) Inasmuch as the nature of a substance depends upon the nature of its molecules, it follows that a physical change is one that does not affect the identity of a substance. A piece of marble may be ground to powder, but each grain is marble still. Ice may change to water and water to steam, yet the identity of the substance is unchanged. A piece of glass may be electrified and a piece of iron magnetized, but they still remain glass and iron. These changes all leave the composition and nature of the molecule unchanged; they are physical changes.

11. What is a Chemical Change?—*A chemi-*

cal change is one that does change the identity of the molecule.

(*a.*) If the piece of marble be acted upon by sulphuric acid, a brisk effervescence takes place caused by the escape of carbonic acid gas which was a constituent of the marble; calcium sulphate (gypsum), not marble, will remain. The water may, by the action of electricity, be decomposed into two parts of hydrogen and one of oxygen. The nature of the glass and iron may easily be changed. These change the nature of the molecule; they are chemical changes.

12. Definition.—*Physics, or Natural Philosophy, is the branch of science that treats of the laws and physical properties of matter, and of those phenomena that depend upon physical changes.*

Recapitulation.—To be reproduced and amplified by the pupil for review.

Matter.		Divisions.	Attractions.	Motions.
PHYSICAL SCIENCE.	PHYSICS.....	MASSES.	GRAVITATION.	*Mechanical Power.*
		MOLECULES.	COHESION. ADHESION.	*Heat.* *Light.* *Electricity.* *Magnetism.*
	CHEMISTRY.	ATOMS......	CHEMISM OR AFFINITY.	(?)

CHANGES.	PHYSICAL. CHEMICAL.

SECTION II.

THE PROPERTIES OF MATTER.

13. Properties of Matter.—*Any quality that belongs to matter or is characteristic of it is called a property of matter.*

Properties of matter are of two classes, physical and chemical.

14. What are Physical Properties?—*Physical properties are such as may be manifested without changing the identity of the molecule* (§ 10).

(*a.*) A piece of coal takes up room, it is hard and heavy, it cannot move itself. These several qualities or properties the coal may exhibit and still remain coal, or still retain its identity. They are, therefore, physical properties of coal.

15. What are Chemical Properties?—*Chemical Properties are such as cannot be manifested without changing the identity of the molecule* (§ 11).

(*a.*) A piece of coal may be burned; therefore combustibility is a property of the coal. This property has been held by the coal for countless ages, but it never has been shown. Further, this piece of coal never can show this property of combustibility without ceasing to exist as coal, without losing its identity. When the coal is burned, the molecules are changed from coal or carbon to carbonic acid gas (CO_2).

16. Experiment.—Take a piece of ordinary sulphur (brimstone) and attempt to pull it in pieces; the degree of its resistance to this effort, or its *tenacity*, measures the attraction of the molecules for each other. Strike it with a hammer, and it breaks into many pieces, thus manifesting its *brittleness;* but each piece is ordinary sulphur. Heat it in a spoon, and it assumes the liquid form, but it is sulphur yet. In none of these changes has the nature of the molecule, or the identity of the substance, undergone any change. On the other hand, if the sulphur be heated sufficiently it will take fire and burn, producing the irritating, suffocating gas familiar to all through the use of common matches. We thus see that the sulphur is combustible. This combustibility is a chemical property, in the *manifestation* of which the identity of the substance is destroyed. Before the manifestation we had sulphur; after it we have sulphurous anhydride (SO_2). The original molecules were elementary, composed of like atoms; the resultant molecules are compound, composed of unlike atoms, sulphur and oxygen.

17. Division of Physical Properties.—Physical properties of matter are, in turn, divided into two classes, *universal* and *characteristic.*

18. What are Universal Properties?—*Universal properties of matter are such as belong to all matter.*

All substances possess them in common; no body can exist without them. We cannot even imagine a body that does not require space for its existence. This quality of matter, which will soon be named, is, therefore, universal.

19. What are Characteristic Properties?—*Characteristic properties of matter are such as belong to matter of certain kinds only.*

They enable us to distinguish one substance from another. Glass is brittle, and by this single property may be distinguished from india-rubber.

20. List of Universal Properties.—The principal universal properties of matter are *extension, impenetrability, weight, indestructibility, inertia, mobility, divisibility, porosity, compressibility, expansibility, and elasticity.*

21. List of Characteristic Properties.—The characteristic properties of matter (often called *specific* or *accessory properties*) are numerous. They depend, for the most part, upon cohesion and adhesion. The most important characteristic properties are *hardness, tenacity, brittleness, malleability, ductility.*

22. What is Extension?—*Extension is that property of matter by virtue of which it occupies space.*

It has reference to the qualities of length, breadth, and thickness. It is an essential property of matter, involved in the very definition of matter.

(*a.*) All matter must have these three dimensions. We say that a line has length, a surface has length and breadth; but lines and surfaces are mere conceptions of the mind, and can have no material existence. The third dimension, which affords the idea of solidity or volume, is necessary to every form of every kind of matter. No one can imagine a body that has not these three dimensions, that does not occupy space, or "take up room." Figure or shape necessarily follows from extension.

23. English Measures.—For the purpose of comparing volumes, as well as surfaces and lengths, measures are necessary. In the United States and England the *yard* has been adopted as the unit, and its divisions, as feet and inches, together with its multiples, as rods and miles, are in familiar use. This unit is determined by certain bars, carefully preserved by the governments of these two nations.

24. Metric Measures.—The international system has the merits of a less arbitrary foundation and of far greater convenience. From its unit it is known as the metric system. This system is in familiar use in most of the countries of continental Europe and by scientific writers of all nations, and bids fair to come into general use in this country. For these reasons, as well as for its greater convenience, an acquaintance with this system is now desirable, and will soon be necessary. It has been already legalized by act of Congress.

25. Definition of Meter.—The meter is defined as the *forty-millionth of the earth's meridian* which passes through Paris, or as the ten-millionth of a quadrant of such a meridian. It is *equal to 39.37 inches.* Like the Arabic system of notation and the table of U. S. Money, its divisions and multiples vary in a tenfold ratio.

26. Metric Measures of Length.—Ratio = 10.

DIVISIONS.	*Millimeter*	(*mm.*) =	.001 *m.* =	0.03937	inches.
	Centimeter	(*cm.*) =	.01 *m.* =	0.3937	"
	Decimeter	(*dm.*) =	.1 *m.* =	3.937	"
UNIT.	*Meter*	(*m.*) =	1. *m.* =	39.37	"
MULTIPLES.	Dekameter	(*Dm.*) =	10. *m.* =	393.7	"
	Hektometer	(*Hm.*) =	100. *m.* =	328 ft. 1 inch.	
	Kilometer	(*Km.*) =	1000. *m.* =	0.62137	miles.
	Myriameter	(*Mm.*) =	10000. *m.* =	6.2137	"

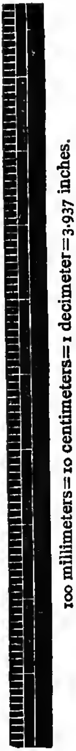


FIG. 1.

Note.—The table may be read: 10 millimeters make 1 centimeter; 10 centimeters make 1 decimeter, etc. The denominations most used in practice are printed in italics. The system of nomenclature is very simple. The Latin prefixes, *milli-*, *centi-*, and *deci-*, signifying respectively $\frac{1}{1000}$, $\frac{1}{100}$, and $\frac{1}{10}$, and already familiar in the mill, cent, and dime of U. S. Money, are used for the divisions, while the Greek prefixes *deka-*, *hekto-*, *kilo-*, and *myria-*, signifying respectively 10, 100, 1000, and 10000, are used for the multiples of the unit. Each name is accented on the first syllable.

27. Metric Measures of Surface.—Ratio = 10^2 = 100.

DIVISIONS.	Square millimeter	(*sq. mm.*)=0.000001	*sq. m.*
	Square centimeter	(*sq. cm.*) =0.0001	"
	Square decimeter	(*sq. dm.*) =0.01	"
UNIT.	Square meter	(*sq. m.*) =1.	"
	etc., etc.		

Note.—The table may be read: 100 *sq. mm.* = 1 *sq. cm.*; 100 *sq. cm.* = 1 *sq. dm.*, etc. The reason for the change of ratio from 10 to 100 may be clearly shown by representing 1 *sq. dm.*, and dividing it into *sq. cm.* by lines, which shall divide each side of the *sq. dm.* into 10 equal parts or centimeters.

28. Metric Measures of Volume.—Ratio = 10^3 = 1000.

DIVISIONS.	Cubic millimeter	(*cu. mm.*) = 0.000000001	*cu. m.*
	Cubic centimeter	(*cu. cm.*) = 0.000001	"
	Cubic decimeter	(*cu. dm.*) = 0.001	"
UNIT.	*Cubic meter*	(*cu. m.*) = 1.308 cu. yds.	
	etc., etc.		

29. Metric Measures of Capacity.—Ratio = 10.—For many purposes, such as the measurement of articles usually sold by dry and liquid measures, a smaller unit than the cubic meter is desirable. For such purposes the *cubic decimeter* has been selected as the standard, and when thus used *is called a liter* (pronounced *leeter*).

DIVISIONS.	Milliliter	(*ml.*) =	1 cu. cm.	= 0.061022 cu. in.
	Centiliter	(*cl.*) =	10 "	= 0.338 fld. oz.
	Deciliter	(*dl.*) =	100 "	= 0.845 gill.
UNIT.	*Liter*	(*l.*) =	1000 "	= 1.0567 liquid qts.
MULTIPLES.	Dekaliter	(*Dl.*) =	10 cu. dm.	= 9.08 dry qts.
	Hektoliter	(*Hl.*) =	100 cu. dm.	= 2 bu. 3.35 pks.
	Kiloliter	(*Kl.*) =	1 cu. m.	= 264.17 gals.

30. Comparative Helps.—It may be noticed that the *m.* corresponds somewhat closely to the yard, which it will replace. Kilometers will be used instead of miles. The *cu. cm.* may be represented by the ordinary die used in playing backgammon. The *l.* does not differ very much from the quart, or the *Dl.* from the peck, which they will respectively replace. In fact, the *l.* is, in capacity, intermediate between the dry and liquid quarts.

31. What is Impenetrability?—*Impenetrability is that property of matter by virtue of which two bodies cannot occupy the same space at the same time.*

(*a.*) Illustrations of this property are very simple and abundant. Thrust a finger into a tumbler of water; it is evident that the water and the finger are not in the same place at the same time. Drive a nail into a piece of wood; the particles of wood are either crowded more closely together to give room for the nail, or some of them are driven out before it. Clearly, the iron and the wood are not in the same place at the same time.

32. Experiment.—Through one cork of a two-necked bottle pass a small funnel or "thistle-tube," and let it extend nearly to the bottom of the bottle. Through the other cork lead a tube to the water-pan, and let it terminate beneath or within the neck of a clear glass bottle filled with water, and inverted in the water-pan. See that the corks are air-tight; if necessary, seal them with wax or plaster of Paris. If a two-necked bottle be not convenient, substitute therefor a wide-mouthed bottle having two holes through the cork. The delivery tube is best made of glass. It may be easily bent by first heating it red-hot in an alcohol or gas flame. Pour water steadily through the funnel; as it descends, air is forced out through the delivery tube, and may be seen bubbling through the water in the inverted bottle. At the end of the experiment, the volume of water in the two-necked bottle will be nearly equal to the volume of air in the inverted bottle. This clearly shows the impenetrability of air.

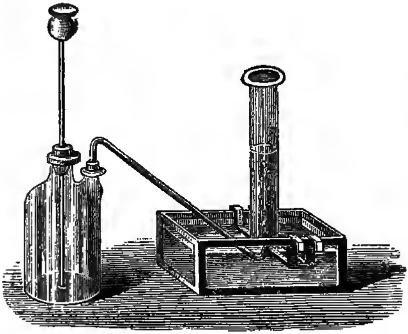


FIG. 2.

33. What is Weight?—*Weight is* (as the term is generally used) *the measure of gravity* or molar attraction (§ 7) of which it is a necessary consequence.

(*a.*) As all masses of matter exert this force, weight necessarily pertains to *all* matter; but, in general use, the term weight has reference to bodies upon the earth. If a body be placed near the earth's surface and left unsupported, the mass-attraction of the earth for each molecule in the body will draw the two together, and the body is said to fall to the earth. But in this case we have no means of measuring the force that draws the two bodies together. If now the body be supported, the force acts as before and produces pressure upon the supporting substance. This pressure measures the attractive force acting between the earth and the body, and is called *weight.* If a second body like the first be placed beside it, the mass-attraction of the earth is exerted upon twice as many molecules, and, reciprocally, the attraction of twice as many molecules is exerted upon the earth; *i. e.*, the attraction has become twice as great, and the measure of that attraction, or the weight, has been doubled.

(*b.*) If the same body were upon the moon, its weight would be the measure of the attraction existing between the body and the moon. But as the mass of the moon is less than that of the earth, the attraction between the body and the moon would be less than that between that body and the earth, and the weight would be proportionally diminished.

34. English Measures of Weight.—For the comparison of weights, as well as of extension, standards are necessary. In England and the United States the pound is taken as the unit. Unfortunately, we have pounds Troy, Avoirdupois, and Apothecaries', the use varying with the nature of the transaction. As with the yard, these units are arbitrary, determined by certain carefully preserved standards.

35. Metric Measures of Weight.—Ratio = 10.

DIVISIONS.	Milligram	(*mg.*)	=	0.0154	grains.	
	Centigram	(*cg.*)	=	0.1543	"	
	Decigram	(*dg.*)	=	1.5432	"	
UNITS.	*Gram*	(*g.*)	=	15.432	"	
MULTIPLES.	Dekagram	(*Dg.*)	=	0.3527	oz.	avoirdupois.
	Hektogram	(*Hg.*)	=	3.5274	"	"
	Kilogram	(*Kg.*)	=	2.2046	lbs.	"
	Myriagram	(*Mg.*)	=	22.046	"	"

36. What is a Gram?—*A gram is the weight of one cu. cm. of pure water,* at its temperature of greatest density (4° C. or 39.2° F.). A 5-cent nickel coin weighs 5 g.

EXERCISES.

1. How much water, by weight, will a liter flask contain?
2. If sulphuric acid is 1.8 times as heavy as water, what weight of the acid will a liter flask contain?
3. If alcohol is 0.8 times as heavy as water, how much will 1250 *cu. cm.* of alcohol weigh?
4. What part of a liter of water is 250 *g.* of water?
5. What is the weight of a *cu. dm.* of water?
6. What is the weight of a *dl.* of water?

37. What is Indestructibility?—*Indestructibility is that property of matter by virtue of which it cannot be destroyed.*

(*a.*) Science teaches that the universe, when first hurled into space from the hand of the Creator, contained the same amount of matter, and even the same quantity of each element, that it contains to-day. This matter has doubtless existed in different forms, but during all the ages since, not one atom has been gained or lost. Take carbon for instance. From geology we learn that in the carboniferous age, long before the advent of man upon the earth, the atmosphere was highly charged with carbonic acid gas, which, being absorbed by plants, produced a vegetation rank and luxuriant beyond comparison with any now known. The carbon thus changed from the gaseous to the solid form was, in time, buried deep in the earth, where it has lain for untold centuries, not an atom lost. It is now mined as coal, burned as fuel, and thus transformed again to its original gaseous form. No human being can create or destroy a single atom of carbon or of any other element. Matter is indestructible. Water evaporates and disappears only to be gathered in clouds and condense and fall as rain. Wood burns, but the ashes and smoke contain the identical atoms of which the wood was composed. In a different form, the matter still exists and weighs as much as before the combustion.

38. What is Inertia?—*Inertia is that property of matter by virtue of which it is incapable* *of changing its condition of rest or motion,* or the property by virtue of which it has a tendency when at rest to remain at rest, or when in motion to continue in motion.

(*a.*) If a ball be thrown, it requires external force to put it in motion; the ball cannot put itself in motion. When the ball is passing through the air it has no power to stop, and it will not stop until some external force compels it to do so. This external force may be the bat, the catcher, the resistance of the air, or the force of gravity. It must be something *outside the ball* or the ball will move on forever. Illustrations of the inertia of matter are so numerous that there should be no difficulty in getting a clear idea of this property. The "running jump" and "dodging" of the playground, the frequent falls which result from jumping from cars in motion, the backward motion of the passengers when a car is suddenly started and their forward motion when the car is suddenly stopped, the difficulty in starting a wagon and the comparative ease of keeping it in motion, the "balloon" and "banner" feats of the circus-rider, etc., etc., may be used to illustrate this property of matter.

39. Experiment.—Upon the tip of the fore-finger of the left hand, place a common calling-card. Upon this card, and directly over the finger, place a cent. With the nail of the middle finger of the right hand let a sudden blow or "snap" be given to the card. A few trials will enable you to perform the experiment so as to drive the card away, and leave the coin resting upon the finger. Repeat the experiment with the variation of a bullet for the cent, and the open top of a bottle for the finger-tip.

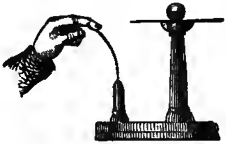


FIG. 3.

40. What is Mobility?—*Mobility is that property of matter by virtue of which the position of bodies may be changed.*

(*a.*) A body is any separate portion of matter, be it large or small, as a book, a table, or a star. The term is nearly synonymous with mass, but has not so distinct a reference to the absolute quantity of matter. Bodies or masses are composed of molecules; molecules are composed of atoms.

(*b.*) On account of inertia, the body cannot change its own position; on account of mobility any mass of matter may be moved if sufficient force be applied. This changing of position is called *motion;* motion presupposes force. (See § 64.)

41. What is Divisibility?—*Divisibility is that property of matter by virtue of which a body may be separated into parts.*

(*a.*) Theoretically, the atom is the limit of divisibility of matter. Practically the divisibility of matter is limited before the molecule is reached; our best instruments are not sufficiently delicate, our best trained senses are not acute enough for the isolation or perception of a molecule. Nevertheless, this divisibility may be carried to such an extent, by natural, mechanical (physical) or chemical means, as to excite our wonder and test the powers of imagination itself. It is said that the spider's web is made of threads so fine that enough of this thread to go around the earth would weigh but half a pound, and that each thread is composed of six thousand filaments. A single inch of this thread with all its filaments may be cut into thousands of distinct pieces, and each piece of each filament be yet a mass of matter composed of molecules and atoms. The microscope reveals to us the existence of living creatures so small that it would require thousands of millions of them to aggregate the size of a hemp-seed. Yet each animalcule has organs of absorption, etc.; in some of these organs fluids circulate or exist. How small must be the molecules of which these fluid *masses* are composed! What about the size of the atoms which constitute the molecules? A coin in current use loses, in the course of a score of years, a perceptible quantity of metal by abrasion. What finite mind can form a clear idea of the amount of metal rubbed off at each transfer?

42. What is Porosity?—*Porosity is that property of matter by virtue of which spaces exist between the molecules.*

(*a.*) When iron is heated, the molecules are pushed further apart, the pores are enlarged, and we say that the iron has expanded. If a piece of iron or lead be hammered, it will be made smaller, because the molecules are forced nearer together, thus reducing the size of the pores. Cavities or cells, like those of bread or sponge, are sometimes spoken of as "sensible pores," but these are not properly included under this head.

43. What is Compressibility?—*Compressibility is that property of matter by virtue of which a body may be reduced in size.*

44. What is Expansibility?—*Expansibility is that property of matter by virtue of which a body may be increased in size.*

(*a.*) Compressibility and expansibility are the opposites of each other, resulting alike from porosity. Illustrations have been given under the head of porosity. Let each pupil prove by experiment that air is compressible and expansible.

45. What is Elasticity?—*Elasticity is that property of matter by virtue of which bodies resume their original form or size when that form or size has been changed by any external force.*

(*a.*) All bodies possess this property in some degree, because all bodies, solid, liquid or aeriform, when subjected to pressure (within limits varying with the substance), will resume their original size upon the removal of the pressure. The amount of compression matters not except in the case of solids. It was formerly thought that liquids were incompressible; hence aeriform bodies were called elastic fluids, while liquids were called non-elastic fluids. But the compressibility and perfect elasticity of liquids having been shown, the term "non-elastic fluid" involves a contradiction of terms and would better be dropped. Fluids have no elasticity of form; on the other hand, all fluids have perfect elasticity of size. What properties of matter are illustrated by the action of the common pop-gun?

46. What are Cohesion and Adhesion?—*Cohesion is the force that holds together like mole-*

cules; adhesion is the force that holds together unlike molecules.

FIG. 4.

(*a.*) Cohesion is the force that holds most substances together and gives them form. Were cohesion suddenly to cease, brick and stone and iron would crumble to finest powder, and all our homes and cities and selves fall to hopeless ruin. In aeriform bodies, cohesion is not apparent, being overcome by molecular repulsion (heat). In large masses of liquids the cohesive force is overcome by gravity, which tends to bring all the molecules as low as possible and thus renders their surfaces level. But in small masses of liquids, the cohesive force predominates and draws all the molecules as near each other as possible, and thus gives to each mass the spheroidal form, as in the case of the dew or rain-drop. Globules of mercury upon the hand or table, and drops of water upon a heated stove, are familiar illustrations of this effect of cohesion upon small liquid masses. But in the solid state of matter, cohesion shows most clearly. Cohesion acts only at insensible (molecular) distances. Let the parts of a body be separated by a sensible distance, and cohesion ceases to act; we say that the body is broken. If the molecules of the parts can again be brought within molecular distance of each other, cohesion will again act and hold them there. This may be done by simple pressure, as in the case of wax or freshly-cut lead; it may be done by welding or melting, as in the case of iron. Circular plates of glass or metal, about three inches in diameter, often have their faces so accurately fitted to each other that, when pressed together, a considerable force is needed to separate them. (See Fig. 4.)

(*b.*) Adhesion is the force that causes the pencil or crayon to leave traces upon the paper or blackboard, and gives efficacy to paste, glue, mortar and cements generally. In a brick wall, cohesion binds together the molecules of the mortar layer into a single, hardening mass, while on either hand adhesion reaches out and grasps the adjoining bricks and holds them fast—a solid wall. Like cohesion, it acts only through distances too small to be measured; unlike cohesion, it acts between unlike molecules.

47. What is Hardness?—*Hardness is that property of matter by virtue of which some bodies resist any attempt to force a passage between their particles.*

It is measured by the degree of difficulty with which it is scratched by another substance. Fluids are not said to have hardness.

(*a.*) Hardness does not imply density. The diamond is much harder than gold, but gold is four times as dense as diamond.

48. What is Tenacity?—*Tenacity is that property of matter by virtue of which some bodies resist a force tending to pull their particles asunder.*

(*a.*) Like hardness and the other characteristic properties of matter, it is a variety of cohesion which is the general term for the forcé which holds the molecules together and prevents disintegration. The tenacity of a substance is generally ascertained by shaping it in the form of a rod or wire, the area of whose cross-section may be accurately measured. Held by one end in a vertical position, the greatest weight which the rod will support is the measure of its tenacity. For any given material, it has been found that *the tenacity is proportioned to the area of the cross-section*; *e. g.*, a rod with a sectional area of a square inch will carry twice as great a load as a rod of the same material with a sectional area of a half square inch; a rod one decimeter in diameter will carry four times as great a load as a similar rod five centimeters in diameter. The explanation of this is simple; *imagine* these rods to be cut across, and it will be evident that, on each side of the cut, the first rod will expose the surfaces of twice as many molecules as will the second, and that the third will expose four times as many molecular surfaces as the fourth. But for the same material, each molecule has the same attractive force. Doubling the number of these attractive molecules, which is done by doubling the sectional area, doubles the total attractive or cohesive force, which, in this case, is called tenacity; quadrupling the sectional area quadruples the tenacity. Hence the law: Tenacity is proportioned to the sectional area.

49. What is Brittleness?—*Brittleness is that property of matter by virtue of which some bodies may be easily broken, as by a blow.*

(*a.*) Glass furnishes a familiar example of this property. The idea that brittleness is the opposite of hardness, elasticity or tenacity, should be guarded against. Glass is harder than wood, but very brittle; it is very elastic, but very brittle also. Steel is far more tenacious than lead, and far more brittle.

50. What is Malleability?—*Malleability is that property of matter by virtue of which some bodies may be rolled or hammered into sheets.*

(*a.*) Steel has been rolled into sheets thinner than the paper upon which these words are printed. Gold is the most malleable metal, and, in the form of gold leaf, has been beaten so thin that 282,000 sheets, placed one upon the other, would measure but a single inch in height.

51. What is Ductility?—*Ductility is that property of matter by virtue of which some bodies may be drawn into wire.*

(*a.*) Platinum wire has been made $\frac{1}{30000}$ of an inch in diameter. Glass, when heated to redness, is very ductile.

52. Experiment.—Heat the middle of a piece of glass tubing, about six inches long, in an alcohol flame, until red-hot. Roll the ends of the glass slowly between the fingers, and when the heated part is soft, quickly draw the ends asunder. That the fine glass wire thus produced is still a tube, may be shown by blowing through it into a glass of water, and noticing the bubbles that will rise to the surface.

Recapitulation.—To be reproduced and amplified by the pupil from memory.

- PROPERTIES OF MATTER.
  - CHEMICAL.
  - PHYSICAL.
    - GENERAL.....
      - *Extension, Impenetrability, Weight, Indestructibility, Inertia, Mobility, Divisibility, Porosity, Compressibility, Expansibility, Elasticity.*
    - CHARACTERISTIC.
      - ADHESION.
      - COHESION.
        - *Hardness.*
        - *Tenacity.*
        - *Brittleness.*
        - *Malleability.*
        - *Ductility.*

SECTION III.

THE THREE CONDITIONS OF MATTER.

53. Conditions of Matter.—*Matter exists in three conditions or forms—the solid, the liquid, and the aeriform.*

54. What is a Solid?—*A solid is a body whose molecules change their relative positions with difficulty.*

Such bodies have a strong tendency to retain any form that may be given to them. A movement of one part of such a body produces motion in all of its parts.

55. What is a Liquid?—*A liquid is a body whose molecules easily change their relative positions, yet tend to cling together.*

Such bodies adapt themselves to the form of the vessel containing them, but do not retain that form when the restraining force is removed. They always so adapt themselves as to have their free surfaces horizontal. Water is the best type of liquids.

56. Experiment.—Suspend a glass or metal plate, of about four inches area, from one end of a scale-beam, and accurately balance the same with weights in the opposite scale-pan. The supporting cords may be fastened to the plate with wax. Beneath

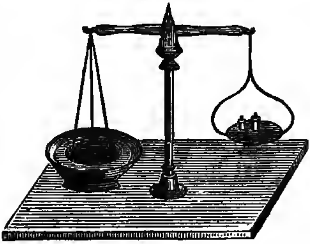


FIG. 5.

the plate place a saucer so that when the saucer is filled with water the plate may rest upon the liquid surface, the scale-beam remaining horizontal. Carefully add small weights to those in the scale-pan. Notice that the water *beneath the plate* is raised above its level. Add more weights until the plate is lifted from the water. Notice that the under surface of the plate is wet. These molecules on the plate have been torn from their companions in the saucer. The weights added to the original counterpoise were needed to overcome the tendency of the water molecules to cling together.

Note to the Pupil.—After seeing a physical experiment, always ask yourself, "What was the object of that experiment? What does it teach?" Never allow yourself to look upon an experiment as being simply entertaining; thus reducing the experimenter, *so far as you are concerned*, to the level of a showman.

57. What is an Aeriform Body?—*An aeriform body is one whose molecules easily change their relative positions, and tend to separate from each other almost indefinitely.*

Atmospheric air is the best type of aëriform bodies.

58. Gases and Vapors.—Aëriform (having the form of air) bodies are of two kinds, *gases* and *vapors.* Gases remain aëriform under ordinary conditions, although they may be liquefied by intense cold and pressure. *Vapors* are aëriform bodies produced by heat from substances that are generally solid or liquid, as iodine or water. They resume the solid or liquid form at ordinary temperatures.

59. Changes of Condition.—The same substance may exist in two or even three of these forms. Most solids, as lead and iron, may be changed by heat to liquids; others, as iodine, may be apparently changed directly to vapors; still others, as ice, may be easily changed first to the liquid, and then to the vapor form. It is probable that any solid might be liquefied and vaporized by the application of heat, and that the practical infusibility of certain substances is due to our limited abilities in the production of heat.

(*a.*) Many vapors and gases, as steam and sulphurous anhydride (SO_2, the irrespirable gas formed by burning sulphur), may be liquefied by cold, the withdrawal of heat. The process is one of subtraction. A still further diminution of the heat force would, in many cases, lead to a solidifying of the liquid. It is probable that all gases might be liquefied and all liquids solidified, if we had the power of unlimited withdrawal of heat. In fact, the last of the "permanent gases" has been liquefied already.

(*b.*) Recent experiments with electric discharges in high vacuums (Exp. 71, p. 250), have yielded remarkable results which are held, by some, to show the existence of a fourth condition of matter. For matter in this "ultra-gaseous" state, the name "Radiant Matter" has been proposed.

60. What is a Fluid?—*A fluid is a body whose molecules easily change their relative positions.*

The term comprehends liquids, gases, and vapors.

(*a.*) In a liquid, cohesion is more powerful than repulsion; in an aëriform body, repulsion is the more powerful. The change from the liquid to the aëriform condition is caused by an increase of the velocity of the constituent molecules, such increase of velocity being a thermal effect.

61. Optional Definitions.—(1.) A body possessing any degree of elasticity of form (§ 45) is a solid; a body that possesses no elasticity of form is a fluid.

(2.) A body that can exist in equilibrium under the action of a pressure that is not uniform in all directions is a solid; a body that cannot exist in equilibrium under such conditions is a fluid.

(3.) A fluid that can expand indefinitely so as to fill any vessel, however large, is an aëriform body; a fluid, a small portion of which, when placed in a large vessel, does not expand at once so as to fill the vessel, but remains collected at the bottom, is a liquid.

(4.) A body that has a definite volume and form is a solid; a body that has a definite volume and an indefinite form is a liquid; a body that has an indefinite volume and form is aëriform.

(5.) A gas is an easily compressible fluid.

62. Kinetic Theory of Gases.—A perfect gas consists of free, elastic molecules in constant motion. Each molecule moves in a straight line and with a uniform velocity until it strikes another molecule or the vessel in which the gas is contained. The blows that the molecules thus strike upon the vessel are so numerous that their total effect is a continuous, constant force or *pressure.*

(*a.*) The mean velocity of a hydrogen molecule has been determined as 184260 *cm.* (or more than a mile) per second. If its weight were known, the work that it can do might be easily computed (§ 157). The molecules of other aëriform substances move with smaller velocities.

Recapitulation.—To be reproduced, upon paper or the blackboard, by each pupil.

MATTER
- **SOLIDS.** Molecules change their relative positions with difficulty.
- **FLUIDS.** Molecules change their relative positions easily.
  - **LIQUIDS.** Molecules cling together feebly.
  - **AERIFORM BODIES.** Molecules tend to separate.
    - GASES; *ordinarily aëriform.*
    - KINETIC THEORY.
    - VAPORS; *ordinarily liquid or solid.*

CHAPTER II.

DYNAMICS.—FORCE AND MOTION.—GRAVITATION.—FALLING BODIES.—THE PENDULUM.—ENERGY.

SECTION I.

FORCE AND MOTION.

63. Dynamics.—*Dynamics is that branch of physics which treats of forces and their effects.*

These effects may be of two kinds.

(*a.*) The forces employed may be counterbalanced. If they thus act upon a body at rest, that body will remain at rest; if they act upon a body in motion, the motion will not be changed thereby. The branch of dynamics that treats of forces thus balanced is called *Statics.*

(*b.*) The forces employed may act against the inertia of matter (§ 38), and produce motion or change of motion. The branch of dynamics that treats of forces thus used is called *Kinetics.* If we have a problem relating to the forces that may produce equilibrium in a lever, as in the act of weighing goods, it is a static problem; if a problem refer to the velocity of a falling body, or the amount of work that may be done by the uncoiling of a watch-spring, it is a kinetic problem.

Note.—No attempt will be made to maintain the distinction between the static and kinetic effects of forces.

64. What is Force?—The word *force* is difficult of satisfactory definition. As generally used, *it signifies* *any cause that tends to produce, change or destroy motion.*

It follows from inertia that bodies are incapable of changing their condition of rest or motion. Any cause capable of producing a tendency to change either of these conditions, is called a force. Equal forces will produce equal velocities when applied to the same body for the same time.

(*a.*) We say that the *tendency* of a force acting on a body at rest is to move it. Motion *will* be produced if the body is free to move. This motion may be prevented by the simultaneous action of another force or of other forces. Or the body may be fixed so that a given pull or pressure, *i. e.*, the application of force, will produce no motion. In this case, opposing forces are called into action as soon as the given force begins to act, and thus the new force is neutralized For instance, a small boy may exert all of his muscular power upon a large stone and not lift it at all. The force employed produces no motion. The attraction between the earth and the stone (§ 33) is a force acting in a downward vertical direction. This force is exactly balanced by the upward pressure of the supporting earth or floor (§ 93). If the stone weighs two hundred pounds and the boy lifts fifty pounds, the supporting body exerts an upward pressure of only one hundred and fifty pounds. One quarter of the weight of the stone or a downward force of fifty pounds is thus liberated or called into play by the very act of lifting with a force of fifty pounds. Hence no motion is produced, because an opposing force is called into action as soon as the given force begins to act, and thus the new force is neutralized.

(*b.*) In this case, the greatest opposing force that can be set free or called into play is a force of two hundred pounds, the full weight of the stone. If, therefore, the stone be lifted with a force of more than two hundred pounds, the new force can not be wholly neutralized and motion will take place. If the body be free to move, the smallest conceivable force will overcome the inertia and produce motion.

65. Elements of a Force.—In treating of forces, we have to consider three things:

(1.) *The point of application*, or the point at which the force acts.

(2.) *The direction*, or the right line along which it tends to move the point of application.

(3.) *The magnitude* or value when compared with a given standard, or the relative rate at which it is able to produce motion in a body free to move.

66. Measurement of Forces.—It frequently is desirable to compare the magnitudes of two or more forces. That they may be compared, they must be measured; that they may be measured, a standard of measure or unit of force is necessary. When this unit has been determined upon, the value of any given force is designated by a numerical reference to the unit, just as we refer quantities of weight to the kilogram or pound, or quantities of distance to the meter or yard. The magnitude of any force may be measured by either of two units, which we shall now consider.

67. The Gravity Unit.—The given force may be measured by comparing it with the gravity of some known quantity or mass of matter. This is a very simple and convenient way, and often answers every purpose. *The gravity unit of force is the gravity of any unit of mass.* This unit of mass may be a gram, kilogram, pound, or ton, or any other unit that may be more convenient under the circumstances.

(*a*.) A force is said to be a force of 100 kilograms when it may be replaced by the action of a weight of 100 kilograms. The pressure of steam in a boiler is generally measured, at present, in pounds *per* square inch, that is, by determining the number of pounds with which it would be necessary to load down a movable horizontal square inch at the top of the boiler in order to keep it in place against the pressure of the steam. A cord or rope may be pulled with a certain force. This force is measured by finding out how many pounds suspended by the cord or rope would give it an equal pull or tension.

(*b.*) As we shall see, the force of gravity exerted upon a given mass is variable. A given piece of iron would weigh more at the poles than at the equator. Other variations in the force of gravity are known. When, therefore, scientific accuracy is required, it will not suffice to speak of a force of ten pounds, but we may speak of a force of ten pounds at the sea-level at New York City. The necessary corrections may then be made. But for ordinary purposes, these details may be disregarded.

68. The Absolute Unit.—*The absolute or kinetic unit of force is the force that, acting for unit of time upon unit of mass, will produce unit of velocity.*

The foot-pound-second (F. P. S.) unit of force is the force that, applied to one pound of matter for one second, will produce a velocity of one foot per second.

(*a.*) In all kinetic questions the kinetic unit is far more convenient. Gravity units may easily be changed to kinetic units. At the latitude of New York, the force of gravity acting upon one pound of matter left free to fall will give it a velocity of 32.16 ft. per second for every second that it acts. Consequently, at such latitudes, the gravity unit is equal to 32.16 kinetic units.

69. The Dyne.—Instead of using a unit of force based upon the foot and pound, scientific men are coming to use a similar unit based upon the centimeter and gram. This unit has a definite name. *The dyne is the force that, acting for one second upon a mass of one gram, produces a velocity of one centimeter per second.*

(*a.*) If a body weighing 25 grams acquires in one second a velocity of 30 *cm.*, the moving force was 750 dynes. If it acquires the same velocity in 2 seconds, of course the force was only half as great, or 375 dynes. As the increment of velocity (§ 127) is 980 *cm.*, the weight of a gram equals 980 dynes.

(*b.*) The several units based upon the centimeter, gram and second, constitute a class called (from the initial letters of these words) C. G. S. Units. Thus the dyne is the C. G. S. unit of force.

Note to the Pupil.—We have been speaking of unit of mass, and you have probably had no difficulty in understanding that, by this term, a certain definite quantity of matter is meant. This certain quantity may be *any* quantity that we agree upon as a unit of measure. In this country we have, as yet, no commonly accepted unit of mass. In countries where the metric system of weights and measures is used, the unit of mass is the quantity of matter contained in one *cu. cm.* of pure water at its temperature of greatest density. It will be seen that this definition is independent of gravity, and that it holds good for matter anywhere. The quantity of matter in the unit thus defined is invariable, while the gram, which is its weight (§ 36), is variable. But notwithstanding this, *at any given place*, weight is proportional to mass, and we, therefore, conveniently use weight as a means of estimating mass. We speak without any considerable ambiguity of a pound of matter, because we know that a mass that weighs two pounds at the same place has just twice as much matter as the first, which we may take as a convenient unit of mass.

70. Momentum.—*The momentum of a body is its quantity of motion.*

Its measure is the product of the numbers representing the mass and the velocity.

(*a.*) One tendency of force is to produce motion. In a given time, two units of force will produce twice as much motion as one unit. This doubled momentum or quantity of motion may exist in two units of mass having one unit of velocity, or in one unit of mass with two units of velocity. The momentum of a body having a mass of 20 pounds and a velocity of 15 feet, is twice as great as that of a body having a mass of 5 pounds and a velocity of 30 ft. The momentum of the former is 300; that of the latter, 150. Momentum has reference only to force and inertia. Therefore, when acting upon bodies free to move, equal forces will produce equal momenta whether the bodies acted upon be light or heavy. The unit of momentum has no definite name.

71. Experiment.—Figure 6 represents a piece of apparatus, devised by Ritchie of Boston. It consists of two ball pendulums, one of which weighs twice as much as the other, suspended as represented. The heavier ball contains a spring-hammer, which is held back by a thread. The hammer being thus held back, and the smaller ball resting against its face, the thread is burned, a blow is struck, and an equal force is exerted upon each ball (§§ 72 [3] and 93). The smaller ball will move twice as fast and twice as far as the larger ball, equal forces producing equal momenta.

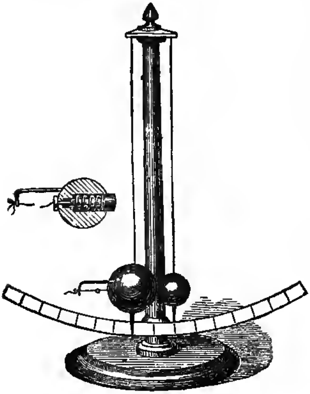


FIG. 6.

EXERCISES.

1. Find the momentum of a 500 lb. ball moving 500 feet a second.

2. By falling a certain time, a 200 lb. ball has acquired a velocity of 321.6 ft. What is its momentum?

3. A boat, that is moving at the rate of 5 miles an hour, weighs 4 tons; another, that is moving at the rate of 10 miles an hour, weighs 2 tons. How do their momenta compare?

4. What is meant by a force of 10 pounds? To how many kinetic units is it equal?

5. A stone weighing 12 oz. is thrown with a velocity of 1320 ft. per minute. An ounce ball is shot with a velocity of 15 miles per minute. Find the ratio between their momenta.

6. An iceberg of 50,000 tons moves with a velocity of 2 miles an hour; an avalanche of 10,000 tons of snow descends with a velocity of 10 miles an hour. Which has the greater momentum?

7. Two bodies weighing respectively 25 and 40 pounds have equal momenta. The first has a velocity of 60 ft. a second; what is the velocity of the other?

8. Two balls have equal momenta. The first weighs 100 kilo-

grams and moves with a velocity of 20 meters a second. The other moves with a velocity of 500 meters a second. What is its weight?

9. A force of 1000 dynes acts on a certain mass for one second and gives it a velocity of 20 cm. *per* second. What is the mass in grams? *Ans.* 50.

10. A constant force, acting on a mass of 12 g. for one second, gives it a velocity of 6 cm. *per* second. Find the force in dynes.

11. A force of 490 dynes acts on a mass of 70 g. for one second. What velocity will be produced? *Ans.* 7.

12. Two bodies start from a condition of rest and move towards each other under the influence of their mutual attraction (§§ 7 and 98). The first has a mass of 1 g.; the second, a mass of 100 g. The force of attraction is $\frac{1}{100}$ dyne. What will be the velocity acquired by each during one second?

72. Laws of Motion.—The following propositions, known as Newton's Laws of Motion, are so important and so famous in the history of physical science that they ought to be remembered by every student:

(1.) Every body continues in its state of rest or of uniform motion in a straight line unless compelled to change that state by an external force.

(2.) Every motion or change of motion is in the direction of the force impressed and is proportionate to it.

(3.) Action and reaction are equal and opposite in direction.

73. The First Law.—The first law of motion results directly from inertia (§ 38). It is impossible to furnish perfect examples of this law because all things within our reach or observation are acted upon by some external force. A base-ball when once set in motion has no power to stop itself (§ 38, *a*). If it moved in obedience to the muscular impulse only, its motion would be in a straight line; but the force of gravity is ever active, and constantly turns it from that line, and forces it to move in a graceful curve instead.

74. Centrifugal Force.—Although it is obviously impossible to give any direct experimental proof of the first law of motion, we see many illustrations of the *tendency* of moving bodies to move in straight lines even when forced to move in curved lines. A curved line may be considered a series of infinitely small straight lines. A body moving in a curve has, by virtue of its inertia, a tendency to follow the prolongation of the small straight line in which it chances to be moving. Such a prolongation becomes a tangent to the curve, to move in which a body must fly further from the centre. *This tendency*

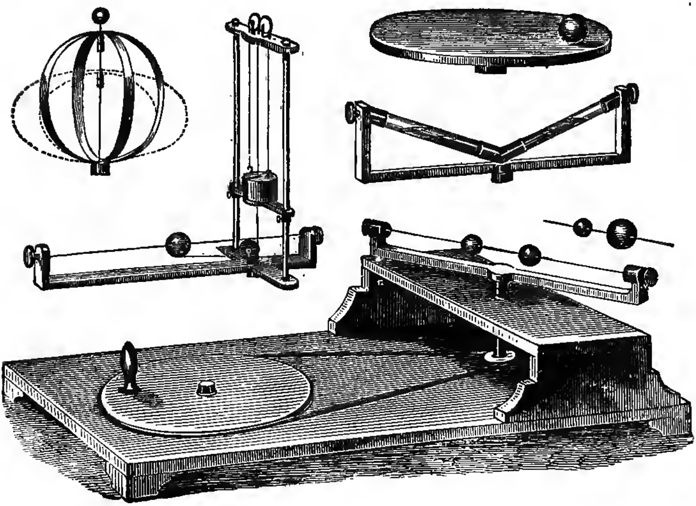


FIG. 7.

of matter to move in a straight line, and, consequently, further away from the centre around which it is revolving, is called Centrifugal Force, from the Latin words which mean to fly from the centre. The "laws" of this "centrifugal force" may be studied or illustrated by the *whirling-table* and accompanying apparatus, represented in Figure 7. (See § 77.)

75. Caution.—It is to be noticed that this so-called *"Centrifugal Force" is not a force at all.* It is simply inertia manifested under special conditions. It is one of the universal properties of matter by virtue of which the body shows a decided determination to obey the first law of motion. The facts of the case are the direct opposite of those implied by this ill-chosen name. Take a common sling, for instance. The *implication* made by the term, "Centrifugal Force," is that the pebble in the revolving sling has a natural tendency to continue moving in a circle, and that some external force is necessary to overcome that tendency. The *truth* is that the natural tendency of the pebble is to move in a straight line, and the only reason that it does not thus move is that it is continually forced from its natural path by the pull of the string. As soon as this external force is removed, by intent or accident, away flies the stone in obedience to its own law-abiding tendencies.

76. Simply Suggestive.—Examples and effects of this so-called centrifugal force may be suggested as follows: Wagon turning a corner, railway curves, water flying from a revolving grindstone, broken fly-wheels, spheroidal form of the earth, erosion of river-beds, a pail of water whirled in a vertical circle, the inward leaning of the circus-horse and rider, the centrifugal drying apparatus of the laundry or sugar refinery, difference between polar and equatorial weights of a given mass, etc.

77. Law of Centrifugal Force.—The force necessary to overcome this tendency of matter to move away from the centre around which it may be revolving, varies directly as the mass and as the square of the velocity, the radius remaining the same. Doubling the mass doubles the force needed, but doubling the velocity quadruples the needed restraining force.

78. The Second Law.—The second law of motion is sometimes given as follows: *A given force will produce the same effect whether the body on which it acts is in motion or at rest; whether it is acted on by that force alone or by others at the same time.*

(*a.*) Many attempts have been made to show that these are only two ways of stating the same proposition; most of them are more perplexing than profitable. In the law as given by Newton (§ 72), the word *motion* is doubtless used in the sense of *momentum.* If the substitution of "momentum" for "motion" makes the reconciliation any easier, no objection can be made to the substitution.

79. Resultant Motion.—*Motion produced by the joint action of two or more forces is called resultant motion.*

The point of application, direction, and magnitude of each of the acting forces being given, the direction and magnitude of the resultant force are found by a method known as the *composition of forces.*

80. Composition of Forces.—Under composition of forces, three cases may arise:

(1.) *When the given forces act in the same direction.* The resultant is then the sum of the given forces. Example: Rowing a boat down stream.

(2.) *When the given forces act in opposite directions.* The resultant is then the difference between the given forces. Motion will be produced in the direction of the greater force. Example: Rowing a boat up stream.

(3.) *When the given forces act at an angle.* The resultant is then ascertained by the parallelogram of forces. Example: Rowing a boat across a stream.

81. Graphic Representation of Forces. — *Forces may be represented by lines,* the point of application determining one end of the line, the direction of the force determining the direction of the line, and the magnitude of the force determining the length of the line.

(*a.*) It will be noticed that these three elements of a force (§ 65) are the ones that precisely define a line. By drawing the line as above indicated, the units of force being numerically equal to the units of length, we have a complete graphic representation of the given force. The unit of length adopted in any such representation may be determined by convenience; but the scale once determined, it must be adhered to throughout the problem. Thus the diagram represents two forces applied to the point B. These forces act at right angles to each other. The arrowheads indicate that the forces represented act from B toward A and C respectively. The force that acts in the direction BA being 20 pounds and the force acting in the direction BC being 40 pounds, the line BA must be one-half as long as BC. The scale adopted being 1 *mm.* to the pound, the smaller force will be represented by a line 2 *cm.* long, and the greater force by a line 4 *cm.* long.

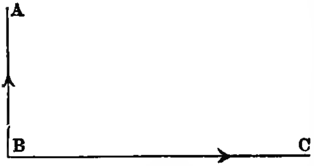


FIG. 8.

(*b.*) The graphic determination or representation of the resultant in the first two cases under the "Composition of Forces" is too simple to need any explanation.

82. Parallelogram of Forces.—In the diagram, let AB and AC represent two forces acting upon the point A. Draw the two dotted lines to complete the parallelogram. From A, the point of application, draw the diagonal AD. *This diagonal will be a complete graphic representation of the resultant.* In such cases the two given forces are called *components.* The resultant of any two components may always be determined in this way. If two forces, such as those represented in the diagram, act simultaneously upon a body at A, that body will move over the path represented by AD, and come to rest at D.

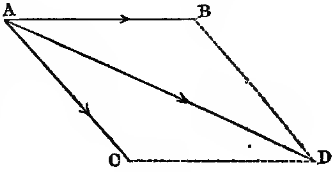


FIG. 9.

(*a.*) Suppose that instead of acting simultaneously, these forces act successively. If AC act first for a given time, it would move the body to C. If then the other force act for an equal time it would move it to the right a distance represented by AB or its equal CD, and the body be left at D as before. If the force represented by AB acted first and the force represented by AC then acted for an equal time, the body would evidently be left at D. Thus we see that these two forces produce the same effect whether they act simultaneously or successively.

83. Experimental Verification.—This principle of the parallelogram of forces may be verified by the apparatus represented in Fig. 10. ABCD is a very light wooden frame, jointed so as to allow motion at its four corners. The lengths of opposite sides are equal; the lengths of adjacent sides are in the ratio of two to three. From the corners B and C, light, flexible silk cords pass over the pulleys M and N, and carry weights, W and *w*, of 90 and 60 ounces respectively, the ratio between the

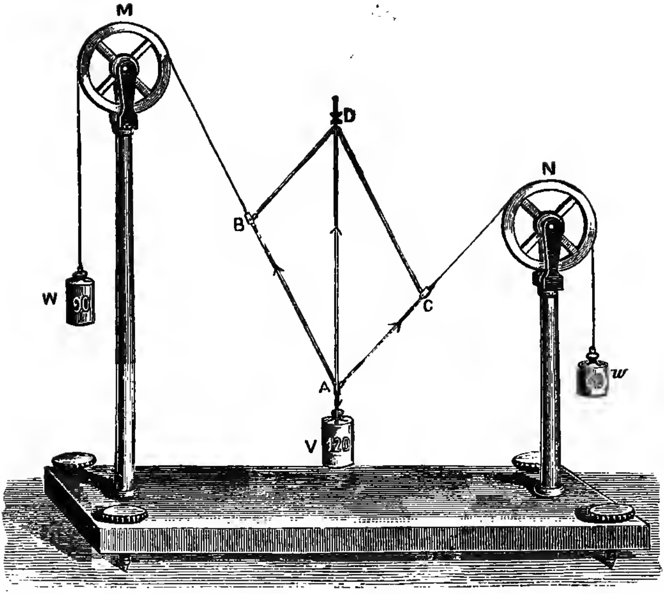


FIG. 10.

weights being the same as the ratio between the corresponding adjacent sides of the wooden parallelogram. A weight of 120 ounces is hung from the corner A. When the wooden frame comes to rest it will be found that the sides AB and AC lie in the direction of the cords which form their prolongations. These sides AB and AC are accurate graphic representations of the two forces acting upon the point A. It will be further found that the diagonal AD is vertical and twice as long as the side AC. Since the side AC represents a force of 60 ounces, AD will represent a force of twice 60 ounces or 120 ounces. We thus see that AD fairly represents the resultant of the two forces due to the gravity of W and *w*, for this resultant is equal, and opposite to the vertical force which is due to the gravity of V, and this balances the forces represented by AB and AC. Results equally satisfactory will be secured as long as AB : AC :: W : *w*.

84. A Substitute.—Very satisfactory results may be had by simpler apparatus. Let H and K represent two pulleys that work with very little friction. Fix them to a vertical board. The blackboard will answer well if the pulleys can be attached without injury. Three silk cords are knotted together at O; two of them pass over the pulleys; the three cords carry weights, P, Q, and R, as shown in the figure. R must be less than the sum of P and Q. When the apparatus has come to rest, take the points A and B so that AO : BO :: P : Q. Complete the parallelogram AOBD by drawing lines upon the vertical board. Draw the diagonal OD. It will be found by measurement that AO : OD :: P : R; or that BO : OD :: Q : R. Either equality of ratios affords the verification sought.

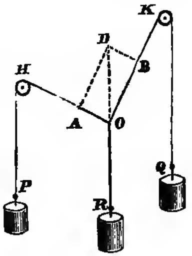


FIG. 11.

85. Determination of the Value of the Resultant.—With a carefully-constructed diagram (only half of the parallelogram need be actually drawn) the resultant may be directly measured and its value ascertained from the scale adopted. The value and direction of the resultant may be found trigonometrically, without actual construction of the diagram, when the angle between the directions of the components is known. In one or two cases, however, the mathematical solution is easy without the aid of trigonometrical formulæ. When the components act at right angles to each other, the resultant is the hypothenuse of a right-angled triangle. (See *Olney's Geometry*, paragraph 346.) When the components are equal and include an angle of 120°, the resultant divides the parallelogram into two equilateral triangles. It is equal to either component, and makes with either an angle of 60°. (Let the pupil draw such a diagram.)

86. Equilibrant.—*A force whose effect is to balance the effects of the several components is called an equilibrant.* It is numerically equal to the resultant, and opposite in direction. Thus in Fig. 10, the gravity of the weight V is the equilibrant of W and *w*; it is equal and opposite to the resultant represented by AD.

87. Triangle of Forces.—By reference to Fig. 9, it will be seen that if AC represent the magnitude and direction of one component, and CD the magnitude and direction of the other component, the line AD, which completes the triangle, will represent the direction and intensity of the resultant. Where the point of application need not be represented, this method of finding the relative magnitudes and directions is more expeditious than the one previously given. If the line which completes the triangle be measured from D to A, that is to say, in the order in which the components were taken, it represents the equilibrant; the arrow-head upon AD should then be turned the other way. If this line be measured from A to D, that is, in the reverse order, it represents the resultant.

88. Composition of More than Two Forces.—If more than two forces act upon the point of application, the resultant of any two may be combined with a third, their resultant with a fourth, and so on. The last diagonal will represent the resultant of all the given forces. Suppose that four forces act upon the point A, as represented in the diagram. By compounding the two forces AB and AC, we get the partial resultant, Ar; by compounding this with AD, we get the second partial resultant, Ar'; by compounding this with AE, we get the resultant, AR.

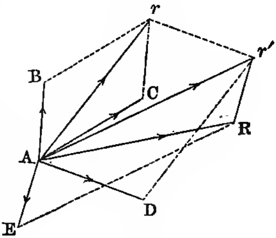


Fig. 12.

89. Polygon of Forces.—This resultant may be more easily obtained by the *polygon of forces.* If a number of forces be in equilibrium, they may be graphically represented by the sides of a closed polygon taken in order. If the forces are not in equilibrium, the lines representing them in magnitude and direction will form a figure which does not close. The line that completes the figure and closes the polygon will, when taken in the same order, indicated by the arrow-head at x, represent the equilibrant; when taken in the opposite order, indicated by the arrow-head at z, it will represent the resultant. This will be evident from a comparison of the diagram with the one preceding, the forces compounded being the same.

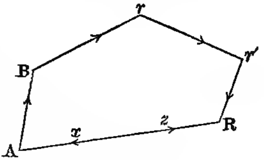


Fig. 13.

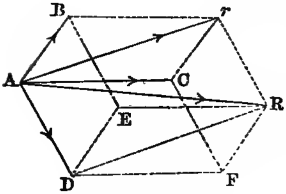


FIG. 14.

90. Parallelopiped of Forces.—The component forces may not all act in the same plane, but the method of composition is still the same. In the particular case of three such forces it will be readily seen that the resultant of the forces AB, AC, and AD is represented by AR, the diagonal of the parallelopiped constructed upon the lines representing these forces.

91. Resolution of Forces.—*The operation of finding the components to which a given force is equivalent is called the resolution of forces.*

It is the converse of the composition of forces. Represent the given force by a line. On this line as a diagonal construct a parallelogram. An infinite number of such parallelograms may be constructed with a given diagonal. When the problem is to resolve or decompose the given force into two or more components *having given directions*, it is definite—only one construction being possible. The sides that meet at the point of application will represent the component forces.

92. Example of Resolution of Forces.—As we proceed we shall find more than one example of the resolution of forces. A single one will answer in this place. It is a familiar fact that a sail-boat may move in a direction widely different from that of the propelling wind, and that, under such circumstances, the velocity of the boat is less than it would be if it were sailing in the direction of the wind. The force due to the pressure of the wind is twice resolved, and only one of the components is of use in urging the boat forward. In Figure 15, let *KL* represent the keel of the boat; *BC*, the position of the sail; and *AB*, the direction and intensity of the wind. In the first place, when the wind strikes the sail thus placed, it is resolved into two components—*BC* parallel to the sail, and *BD* perpendicular to the sail. It is evident that the first of these is of no effect. But the boat does not move in the direction of *BD*, which is, in turn, resolved by the action of the keel and rudder into two forces, *BL* in the direction of the keel, and *BE* perpendicular to it. The first of these produces the forward movement of the boat; the second produces a lateral pressure or tendency to drift, which is more or less resisted by the build of the boat.

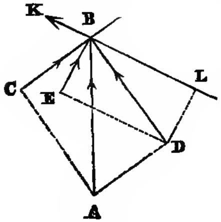


FIG. 15.

93. The Third Law.—Examples of the third law of motion are very common. When we strike an egg upon a table, the reaction of the table breaks the egg; the action of the egg may make a dent in the table. The reaction of the air, when struck by the wings of a bird, supports the bird if the action be greater than the weight. The oarsman urges the water backward with the same force that he urges his boat forward. In springing from a boat to the shore, muscular action tends to drive the boat adrift; the reaction, to put the passenger ashore.

94. Reaction in Non-elastic Bodies.—The effects of action and reaction are modified largely by elasticity, but never so as to destroy their equality. Hang two clay balls of equal mass by strings of equal lengths so that they will just touch each other. If one be drawn aside and let fall against the other, both will move forward, but only half as far as the first would had it met no resistance. The gain of momentum by the second is due to the action of the first. It is equal to the loss of momentum by the first, which loss is due to the reaction of the second.

95. Reaction in Elastic Bodies.—If two ivory balls, which are elastic, be similarly placed, and the experiment repeated, it will be found that the first ball will give the whole of its motion to the second and remain still after striking, while the second will swing as far as the first would have done if it had met no resistance. In this case, as in the former, it will be seen that the first ball loses just as much momentum as the second gains.

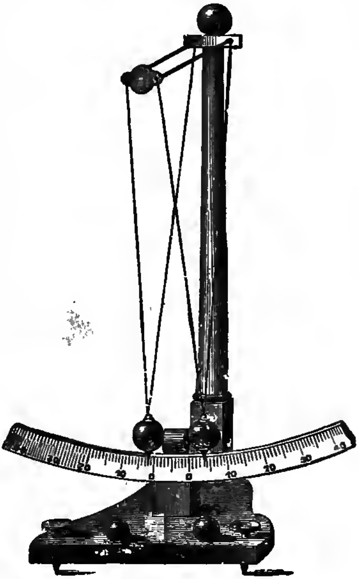


FIG. 16.

96. Reflected Motion.—*Reflected motion is the motion produced by the reaction of a surface when struck by a body, either the surface, or the body, or both being elastic.*

A ball rebounding from the wall of a house, or from the cushion of a billiard-table, is an example of reflected motion.

97. Law of Reflected Motion.—The angle included between the direction of the moving body before it strikes the reflecting surface and a perpendicular to that surface drawn from the point of contact, is called the angle of incidence. The angle between the direction of the moving body after striking and the perpendicular, is called the angle of reflection. *The angle of incidence is equal to the angle of reflection, and lies in the same plane.* A ball shot from *A* will be reflected at *B* back to *C*, making the angles *ABD* and *CBD* equal.

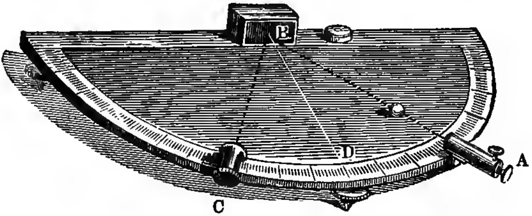


FIG. 17.

EXERCISES. (*Answers to be written.*)

1. Represent graphically the resultant of two forces, 100 and 150 pounds respectively, exerted by two men pulling a weight in the same direction. Determine its value.

2. In similar manner, represent the resultant of the same forces when the men pull in opposite directions. Determine its value.

3. Suppose an attempt be made to row a boat at the. rate of four miles an hour directly across a stream flowing at the rate of three miles an hour. Determine the direction and velocity of the boat.

4. A ball falls 64 feet from the mast of a moving ship to the deck. During the time of the fall, the ship moved forward 24 ft. Represent the actual path of the ball. Find its length.

5. A sailor climbs a mast at the rate of 3 ft. a second; the ship is

sailing at the rate of 12 ft. a second. Over what space does he actually move during 20 seconds?

6. A foot-ball simultaneously receives three horizontal blows; one from the north having a force of 10 pounds; one from the east having a force of 15 pounds, and one from the south-east having a force of 804 kinetic units. Determine the direction of its motion.

7. Why does a cannon recoil or a shot-gun "kick" when fired? Why does not the velocity of the gun equal the velocity of the shot?

8. If the river mentioned in the third problem be one mile wide, how far did the boat move, and how much longer did it take to cross than if the water had been still?

9. A plank 12 feet long has one end on the floor and the other end raised 6 feet. A 50-pound cask is being rolled up the plank. Resolve the gravity of the cask into two components, one perpendicular to the plank to indicate the plank's upward pressure, and one parallel to the plank to indicate the muscular force needed to hold the cask in place. Find the magnitude of this needed muscular force.

10. To how many F. P. S. units of force is the weight of 60 lb. equal?

11. To how many C. G. S. units of force is the weight of 60 *Kg.* equal?

Recapitulation.—To be amplified by the pupil for review.

DYNAMICS.
- **FORCE.**
  - ELEMENTS.
  - MEASUREMENTS.
    - Gravity Unit.
    - Kinetic Unit. *Dyne.*
  - "CENTIFUGAL."
  - GRAPHIC REPRESENTATION.
    - Composition.
      - *Components.*
      - *Resultant.*
      - *Equilibrant.*
      - *Parallelograr*
      - *Triangle.*
      - *Polygon.*
    - Resolution.
- **STATICS.**
- **KINETICS.**
- **MOTION.**
  - MOMENTUM.
  - NEWTON'S LAWS.
  - RESULTANT MOTION.
  - ACTION AND REACTION.
  - REFLECTED MOTION.

SECTION II.

GRAVITATION.

98. What is Gravitation?—*Every particle of matter in the universe has an attraction for every other particle. This attractive force is called gravitation.*

99. Three Important Facts.—In respect to gravitation, three important facts have been established:

(1.) *It acts instantaneously.* Light and electricity require time to traverse space; not so with this force. If a new star were created in distant space, its light might not reach the earth for hundreds or thousands of years. It might be invisible for many generations to come, but its *pull* would be felt by the earth in less than the twinkling of an eye.

(2.) *It is unaffected by the interposition of any substance.* During an eclipse of the sun, the moon is between the sun and the earth. But at such a time, the sun and earth attract each other with the same force that they do at other times.

(3.) *It is independent of the kind of matter, but depends upon the quantity or mass and the distance.* We must not fall into the error of supposing that mass means size. The planet Jupiter is about 1300 times as large as the earth, but it has only about 300 times as much matter because it is only 0.23 as dense.

100. Laws of Gravitation.—(1.) *Gravitation varies directly as the product of the masses.*

(2.) *Gravitation varies inversely as the square of the distance* (between the centres of gravity, § 107).

For example, doubling the product doubles the attraction; doubling the distance, quarters the attraction; doubling both the product and the distance will halve the attraction. Trebling the product will multiply the attraction by three; trebling the distance will divide the attraction by nine; trebling both the product and the distance will divide the attraction by three $\left(\frac{3}{3^2} = \frac{1}{3}\right)$.

101. Equality of Attraction.—*The force exerted by one body upon a second is the same as that exerted by the second upon the first.*

The earth draws the falling apple with a force that gives it a certain momentum; the apple draws the earth with an equal force which gives to it an equal momentum.

102. Gravity.—The most familiar illustration of gravitation is *the attraction between the earth and bodies upon or near its surface.* This particular form of gravitation is commonly called gravity; its measure is weight; its direction is that of the plumb-line, *i. e.*, vertical.

103. Weight.—*The weight of a body varies directly as the mass and inversely as the square of the distance between its centre of gravity and that of the earth.* The mass of the earth remaining constant, doubling the mass of the body weighed doubles the product of the masses (§ 100) and, consequently, doubles the weight. When we ascend from the surface there is nothing to interfere with the working of this law; but when we descend from the surface we leave behind us particles of matter whose attraction partly counterbalances that of the rest of the earth.

104. An Example.—Consider the earth's radius to be 4,000 miles, and the earth's density to be uniform. At the centre, a body, whose weight at the surface is 100 pounds, would be attracted in every direction with equal force. The resultant of these equal and opposite forces would be zero, and the body would have no weight. At 1,000 miles from the centre, one fourth of the distance to the surface, it would weigh 25 pounds, one-fourth the surface weight; at 2,000 miles from the centre, 50 pounds; at 3,000 miles from the centre, 75 pounds; at 4,000 miles from the centre, or the surface distance, it would weigh 100 pounds or the full surface weight. If carried up still further, the weight will decrease according to the square of the distance. At an elevation of 4,000 miles above the surface (8,000 miles from the centre) it will weigh 25 pounds, or one-fourth the surface weight.

105. Law of Weight.—*Bodies weigh most at the surface of the earth. Below the surface, the weight decreases as the distance to the centre decreases. Above the surface, the weight decreases as the square of the distance from the centre increases.*

106. Formulas for Gravity Problems.—Representing the surface weight by W and the surface distance (4,000 miles) by D, the other weight by w, and the other distance from the earth's centre by d, the above law may be algebraically expressed as follows:

Below the earth's surface: $w : W :: d : D$.

Above the earth's surface: $w : W :: D^2 : d^2$.

EXERCISES.

1. How far below the surface of the earth will a ten-pound ball weigh only four pounds?

Solution.

Formula: $w : W :: d : D.$
Substituting: $4 : 10 :: d : 4000$
$d = 1600$, the number of miles from the centre.

$4000 - 1600 = 2400$, the number of miles below the surface.—*Ans.*

2. What would a body weighing 550 lbs. on the surface of the earth weigh 3,000 miles below the surface? *Ans.* $137\frac{1}{2}$ lbs.

3. Two bodies attract each other with a certain force when they are 75 *m.* apart. How many times will the attraction be increased when they are 50 *m.* apart? *Ans.* $2\frac{1}{4}$.

4. Given three balls. The first weighs 6 lbs. and is 25 ft. distant from the third. The second weighs 9 lbs. and is 50 ft. distant from the third. (*a*) Which exerts the greater force upon the third? (*b*) How many times as great? *Ans.* $\frac{8}{3}$.

5. A body at the earth's surface weighs 900 pounds; what would it weigh 8,000 miles above the surface?

6. How far above the surface of the earth will a pound avoirdupois weigh only an ounce? *Ans.* 12,000 miles.

7. At a height of 3,000 miles above the surface of the earth, what would be the difference in the weights of a man weighing 200 lbs. and of a boy weighing 100 lbs.? *Ans.* 32.65 lb.

8. Find the weight of a 180 lb. ball (*a*) 2,000 miles above the earth's surface; (*b*) 2,000 miles below the surface.

9. (*a*) Would a 50 lb. cannon ball weigh more 1,000 miles above the earth's surface, or 1,000 miles below it? (*b*) How much?

10. If the moon were moved to three times its present distance from the earth, what would be the effect (*a*) on its attraction for the earth? (*b*) On the earth's attraction for it?

11. How far below the surface of the earth must an avoirdupois pound weight be placed in order to weigh one ounce?

12. How far above the surface of the earth must 2,700 pounds be placed to weigh 1,200 pounds? *Ans.* 2,000 miles.

13. What effect would it have on the weight of a body to double the mass of the body and also to double the mass of the earth?

107. Centre of Gravity.—*The centre of gravity of a body is the point about which all the matter composing the body may be balanced.*

The force of gravity tends to draw every particle of matter toward the centre of the earth, or downward in a vertical line. We may therefore consider the effect of this force upon any body as the *sum* of an almost infinite number of parallel forces, each of which is acting upon one of the molecules of which that body is composed. We may also consider this sum of forces, or total gravity, as acting upon a single point, just as the force exerted by two horses harnessed to a whiffle-tree is equivalent to another force (resultant) equal to the sum of the forces exerted by the horses, and applied at a single point at or near the middle of the whiffle-tree. This single point, which may thus be regarded as the point of application of the force of gravity acting upon a body, is called the centre of gravity of that body. In other words, the weight of a body may be considered as concentrated at the centre of gravity.

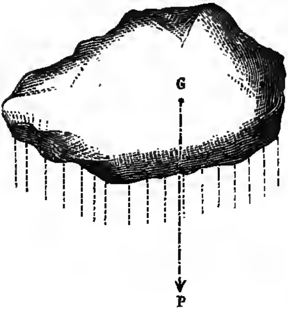


Fig. 18.

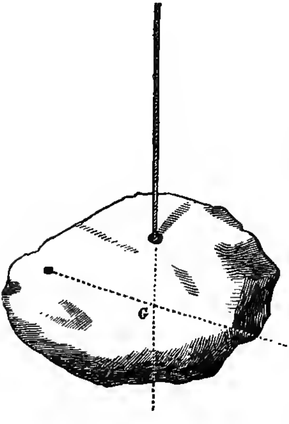


Fig. 19.

108. How to find the Centre of Gravity. — In a freely moving body, the centre of gravity will be brought as low as possible, and will, therefore, lie in a vertical line drawn through the point of support. This fact affords a ready means of determining the centre of gravity experimentally.

Let any irregularly shaped body, as a stone or chair, be suspended so as to move freely. Drop a plumb-line from the point of suspension, and make it fast or mark its direction. The centre of gravity will lie in this line. From a second point, not in the line already determined, suspend the body; let fall a plumb-line as before. The centre of gravity will lie in this line also. But to lie in both lines, the centre of gravity must lie at their intersection. (Fig. 19.)

109. May be Outside of the Body.—The centre of gravity may be outside of the matter of which a body consists, as in the case of a ring, hollow sphere, box, or cask. The same fact is illustrated by the "balancer," represented in the figure. The centre of gravity is in the line joining the two heavy balls, and thus under the foot of the waltzing figure. But the point wherever found will have the same properties as if it lay in the mass of the body. In a freely falling body, no matter how irregular its form, or how indescribable the curves made by any of its projecting parts, the line of direction in which the centre of gravity or point of application moves will be a vertical line (§ 65 [2]).

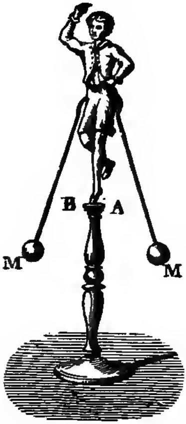


FIG. 20.

110. Equilibrium.—Inasmuch as the centre of gravity is the point at which the weight of a body is concentrated, *when the centre of gravity is supported, the whole body will* *rest in a state of equilibrium.* The centre of gravity will be supported when it coincides with the point of support, or is in the same vertical line with it.

111. Stable Equilibrium.—*A body supported in such a way that, when slightly displaced from its position of equilibrium, it tends to return to that position, is said to be in stable equilibrium.* Such a displacement raises the centre of gravity. Examples: a disc supported above the centre; a semi-spherical oil-can; a right cone placed upon its base; a pendulum or plumb-line. The cavalry-man represented in Fig. 21, is in stable equilibrium, and may rock up and down, balanced upon his horse's hind-feet, because the heavy ball brings the centre of gravity of the combined mass below the points of support. The "balancer" (Fig. 20) affords another example of stable equilibrium.

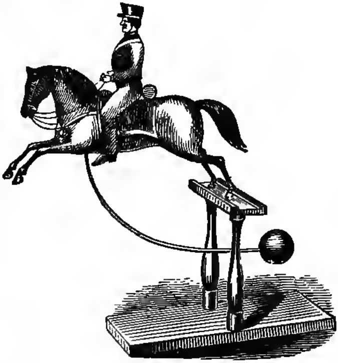


FIG. 21.

112. Unstable Equilibrium.—*A body supported in such a way that, when slightly displaced from its position of equilibrium, it tends to fall further from that position, is said to be in unstable equilibrium.* Such a displacement lowers the centre of gravity. The body will not come to rest until the centre of gravity has reached the lowest possible point, when it will be in stable equilibrium. Examples: A disc supported below its centre; a right cone placed on its apex; an egg standing on its end; or a stick balanced upright upon the finger.

113. Neutral Equilibrium.—*A body supported in such a way that, when displaced from its position of equilibrium, it tends neither to return to its former position nor to fall further from it, is said to be in neutral or indifferent equilibrium.* Such a displacement neither raises nor lowers the centre of gravity. Examples: A disc supported at its centre; a sphere resting on a horizontal surface; a right cone resting on its side.

(*a.*) In the accompanying figure M, N and O represent three cones placed respectively in these three conditions of equilibrium. The letter *g* shows the position of the centre of gravity in each. If a body have two or more points of support lying in the same straight line, the body will be in neutral, stable or unstable equilibrium according as the centre of gravity lies in this line, is directly below it or above it.

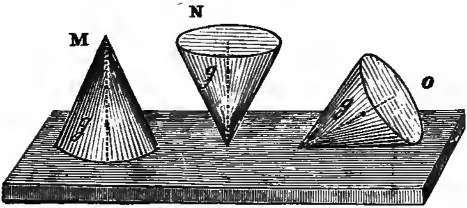


FIG. 22.

114. Line of Direction.—*A vertical line drawn downward from the centre of gravity is called the line of direction.* As we have seen, it represents the direction in which the centre of gravity would move if the body were unsupported. It may be considered as a line connecting the centre of gravity of the given body and the centre of the earth.

115. The Base.—*The side on which a body rests is called its base.* If the body be supported on legs, as a chair, the base is the polygon formed by joining the points of support.

116. Stability.—*When the line of direction falls within the base, the body stands; when without the base, the body falls.*

In the case of the tower represented in Fig. 23, if the upper part be removed, the line of direction will be as shown by the left hand dotted line. It falls within the base, and the tower stands. When the upper part is fastened to the tower, the line of direction is represented by the right hand dotted line. This falls without the base, and the tower falls. The stability of bodies is measured by the amount of work necessary to overturn them. This depends upon the distance that it is necessary to raise the centre of gravity (equivalent to raising the whole body), that the line of direction may fall without the base. When the body rests upon a point, as does the sphere, or upon a line, as does the cylinder, a very slight force is sufficient to move it, no elevation of the centre of gravity being necessary. The broader the base, and the lower the centre of gravity, the greater the stability.

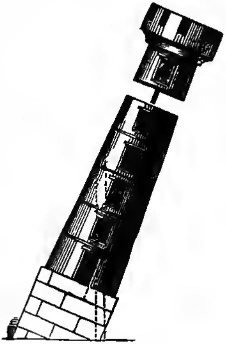


FIG. 23.

117. Illustrations of Stability.—Let the figure represent the vertical section of a brick placed upon its side, its position of greatest stability. In order to stand the brick upon its end, *g*, the centre of gravity must pass over the edge *c*. That is to

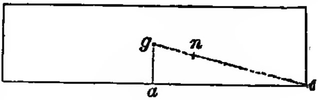


FIG. 24.

say, the centre of gravity must be raised a distance equal to the difference between *ga* and *gc*, or the distance *nc*. But to lift *g* this distance is the same as to lift the whole brick vertically a distance equal to *nc*. Now draw similar figures for the brick when placed upon its edge and upon its end. In each case make *gn* equal to *ga*, and see that the value of *nc* decreases. But *nc* represents the distance that the brick, or its centre of gravity, must be raised before the line of direction can fall without the base, and the body be overturned. To lift the brick, or its centre of gravity, a small distance involves less work than to lift it a greater distance. Therefore, the greater the value of *nc*, the more work required to overturn the body, or the greater its stability. But this greater value of *nc* evidently depends upon a larger base, a lower position for the centre of gravity, or both.

FIG. 25.

(*a*.) These facts explain the stability of leaning towers like those of Pisa and Bologna. In some such towers the centre of gravity is lowered by using heavy materials for the lower part and light materials for the upper part of the structure. It is difficult to stand upon one foot or to walk upon a tight rope because of the smallness of the base. A porter carrying a pack is obliged to lean forward; a man carrying a load in one hand is obliged to lean away from the load, to keep the common centre of gravity of man and load over the base formed by joining the extremities of his feet. Why does a person stand less firmly when his feet are parallel and close together than when they are more gracefully placed? Why can a child walk more easily with a cane than without? Why will a book placed on a desk-lid stay there while a marble would roll off? Why is a ton of stone on a wagon less likely to upset than a ton of hay similarly placed?

Exercises.

Explanatory Note.—The first problem in the table below may be read as follows: What will be the weight of a body which weighs 1200 pounds at the surface of the earth, when placed 2000 miles below the surface? When placed 4000 miles above the surface? (Radius of earth=4000 miles.) All of the measurements are from the surface.

Number of Problem.	Below Surface.		At Surface.	Above Surface.	
	Pounds.	Miles from Surface.	Pounds.	Pounds.	Miles from Surface.
1	?	2000	1200	?	4000
2	300	?	1200	533⅓	?
3	?	3000	800	?	6000
4	?	1000	150	?	1000
5	100	?	400	100	?
6	250	3000	?	?	4000
7	?	1600	?	32	6000
8	12½	?	100	25	?
9	?	3250	480	?	2000
10	90	?	450	50	?
11	160	?	256	?	12000
12	201.6	2600	?	16	?
13	256	?	?	40.96	16000
14	20250	?	324000	9000	?
15	?	3200	?	1280	9000

Recapitulation.—In this section we have considered Gravitation; Facts concerning it; its Law; Gravity; Weight; Law of Weight; Centre of Gravity; Equilibrium and Stability of Bodies.

SECTION III.

FALLING BODIES.

118. A Constant Force.—The tendency of force is generally to produce motion. Acting on a given mass for a given time, a given force will produce a certain velocity. If the same force acts on the same mass for twice the time it will produce a double velocity. *A force which thus continues to act uniformly upon a body, even after the body has begun to move, is called a constant force.* The velocity thus produced is called a uniformly accelerated velocity. If a constant force gives a body a velocity of 10 feet in one second, it will give a velocity of 20 feet in two seconds, of 30 feet in three seconds, and so on. The force of gravity is a constant force and the velocity it imparts to the falling body is a uniformly accelerated velocity.

119. Velocities of Falling Bodies.—If a feather and a cent be dropped from the same height, the cent will reach the ground first. This is not because the cent is heavier, but because the feather meets with more resistance from the air. If this resistance can be removed or equalized, they will fall equal distances in equal times, or will fall with the same velocity. This resistance may be avoided by trying the experiment in a glass tube from which the air has been removed. The resistance may be nearly equalized by making the two falling bodies of the same size and shape but of different weights. Take an iron and a wooden ball of the same size, drop them at the same time from an upper window, and notice that they will strike the ground at sensibly the same time.

FIG. 26.

120. Reason of this Equality.—The cent is heavier than the feather and is therefore acted upon by a greater force. The iron ball has the greater weight, which shows that it is acted upon by a greater force than the wooden ball. But this greater force has to move a greater mass, has to do more work than the lesser force. *For the greater force to do the greater work requires as much time as for the lesser force to do the lesser work.* The working force and the work to be done increase in the same ratio. A regiment will march a mile in no less time than a single soldier would do it; a thousand molecules can fall no further in a second than a single molecule can.

121. Galileo's Device.—To avoid the necessity for great heights, and the interference of rapid motion with accurate observations, Galileo used an inclined plane, consisting of a long ruler having a grooved edge, down which a heavy ball was made to roll. In this way he reduced the velocity, and diminished the interfering resistance of the atmosphere without otherwise changing the nature of the motion. Let AB represent a plane so inclined that the velocity of a body rolling from B toward A will be readily observable. Let C be a heavy ball. The gravity of the ball may be represented by the vertical line CD. But CD may be resolved into CF, which represents a force acting perpendicular to the plane and producing pressure upon it but no motion at all, and CE, which represents a force acting parallel to the plane, the only force of any effect in producing motion. It may be shown geometrically that

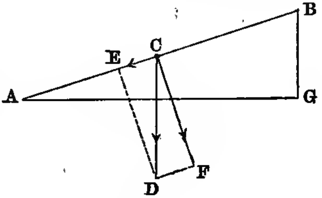


FIG. 27.

EC : CD :: BG : BA. (*Olney's Geometry*, Art. 341.)

By reducing, therefore, the inclination of the plane we may reduce the magnitude of the motion producing component of the force of gravity and thus reduce the velocity. This will not affect the laws of the motion, that motion being changed only in amount, not at all in character.

122. Attwood's Device.

—For the purpose of lessening the velocity of falling bodies without changing the character of the motion, Mr. Attwood devised a machine which has

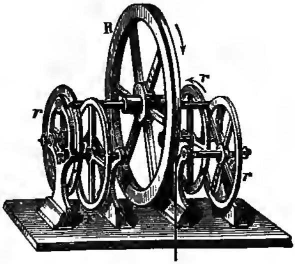
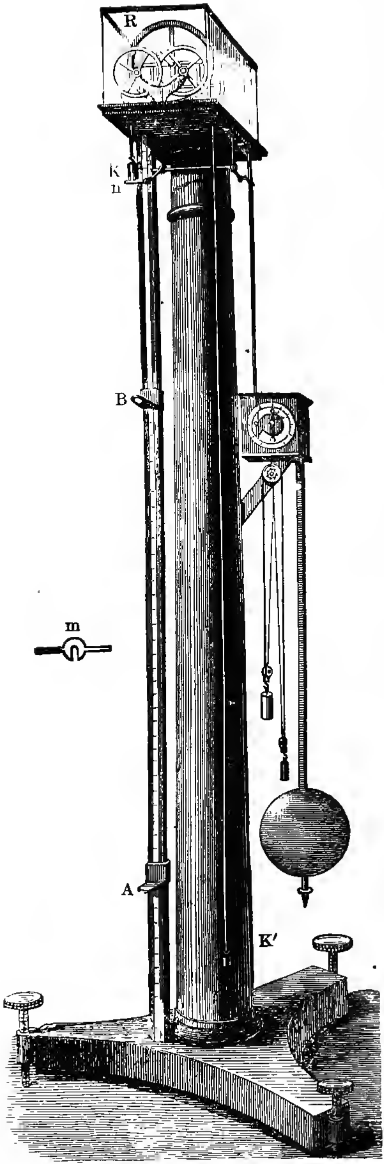


FIG. 28.



taken his name. Attwood's machine consists essentially of a wheel R, about six inches in diameter, over the grooved edge of which are balanced two equal weights, suspended by a long silk thread, which is both light and strong. The axle of this wheel is supported upon the circumferences of four friction wheels, *r, r, r, r*. for greater delicacy of motion. As the thread is so light that its weight may be disregarded, it is evident that the weights will be in equilibrium whatever their position

This apparatus is supported upon a wooden pillar, seven or eight feet high. The silk cord carrying K, one of the weights, passes in front of a graduated rod which carries a movable ring B, and a movable platform A. At the top of the pillar is a plate *n*, which may be fastened in a horizontal position for the support of K at the top of the graduated rod. This plate may also be dropped to a vertical position, thus allowing K, when loaded, to fall. A clock, with a pendulum beating seconds, serves for the measurement of time, and the dropping of the plate at the top of the pillar. A weight or rider, *m*, is to be placed upon K, and give it a downward motion. Levelling screws are provided by means of which the graduated rod may be made vertical, and K be made to pass through the middle of B.

(*a*.) Suppose that K and K′ weigh 315 grams each, and that the rider *m* weighs 10 grams. When *m* is placed upon K and the plate dropped by the action of the clock, the gravity of *m* causes the weights to move. We now have the motion of 640 grams produced by the gravity of only 10 grams. When this force (gravity) moves only 10 grams it will give it a certain velocity. When the same force moves 640 grams it has to do 64 times as much work, and can do it with only $\frac{1}{64}$ the velocity. In this way we are able to give to K and *m* any velocity of fall that we desire.

123. Experiments.—Arrange the apparatus by supporting K and *m* upon the shelf *n*. As the hand of the clock passes a certain point on the dial, 12 for example, the shelf *n* is dropped and the weights begin to move. By a few trials, B may be so placed that at the end of one second it will lift *m* from K, and thus show how far the weights fall in one second. Other experiments will show how many such spaces they will fall in the next second or in two seconds; in the third second or in three seconds; in the fourth second or in four seconds, etc.

Suppose that B lifts off *m* at the end of the first second. The moving force being no longer at work, inertia will keep K moving with the same velocity that it had at the end of the first second. By placing A so that K will reach it at the end of the second second, the distance AB will indicate the velocity with which K was moving when it passed B at the end of the first second. In a similar way the velocity at the end of the second, third, or fourth second may be found.

124. Results.—Whatever the space passed over in the first second by the weights or the ball, it will be found that there is an uniform increase of velocity. Galileo found that if the plane was so inclined that the ball would roll one foot during the first second, it would roll three feet during the next second, five feet during the third, and so on, the common difference being two feet, or twice the distance traversed in the first second.

He found that under the circumstances supposed, the ball would have a velocity of two feet at the end of the first second, of four feet at the end of the next, of six feet at the end of the third, and so on, the increase of velocity during the first second being the same as the increase during any subsequent second.

He found that, under the circumstances supposed, the ball would pass over one foot during one second, four feet during two seconds, and nine feet during three seconds, and so on. Similar results may be obtained with Attwood's machine.

125. Table of Results.—These results are generalized in the following table, in which t represents any given number of seconds:

Number of Seconds.	*Spaces fallen during each Second.*	*Velocities at the End of each Second.*	*Total Number of Spaces fallen.*
1	1	2	1
2	3	4	4
3	5	6	9
4	7	8	16
etc.	etc.	etc.	etc.
t	$2t-1$	$2t$	t^2

126. Unimpeded Fall.—By transferring matter from K′ to K, the velocity with which the weights move will be increased. When all of K′ has been transferred to K, *the weights will fall, in this latitude, 16.08 ft. or 4.9 m. during the first second.*

If the plane be given a greater inclination, the ball will, of course, roll more rapidly and our unit of space will increase from one foot, as supposed thus far, to two, three, four or five feet, and so on, but the *number* of such spaces will remain as indicated in the table above. By disregarding the resistance of the air, we may say that when the plane becomes vertical, the body becomes a freely falling body. Our unit of space has now become 16.08 ft. or 4.9 *m.* It will fall this distance during the first second, three times this distance during the next second, five times this distance during the third second, and so on.

127. Increment of Velocity.—*During the first second the freely falling body will gain a velocity of 32.16 feet.* It will make a like gain of velocity during each subsequent second of its fall. This distance is therefore called the increment of velocity due to gravity, and is generally represented by $g = 32.16$ ft. or 9.8 *m.*

Note—This value must not be forgotten.

128. Formulas for Falling Bodies.—If now we represent our space by $\frac{1}{2}g$, the velocity at the end of any second by v, the number of seconds by t, the spaces fallen each second by s, and the total space fallen through by S, we shall have the following formulas for freely falling bodies:

$$(1.)\quad v = gt \text{ or } \tfrac{1}{2}g \times 2t.$$

$$(2.)\quad s = \tfrac{1}{2}g\,(2t - 1).$$

$$(3.)\quad S = \tfrac{1}{2}g\,t^2.$$

129. Laws of Falling Bodies.—These formulas may be translated into ordinary language as follows:

(1.) The velocity of a freely falling body at the end of any second of its descent is equal to 32.16 ft. (9.8 *m.*) multiplied by the number of the second.

(2.) The distance traversed by a freely falling body during any second of its descent is equal to 16.08 ft. (4.9 *m.*) multiplied by one less than twice the number of seconds.

(3.) The distance traversed by a freely-falling body during any number of seconds is equal to 16.08 ft. (4.9 *m.*) multiplied by the square of the number of seconds.

130. For Bodies Rolling Down an Inclined Plane.—If the body be rolling down an inclined plane instead of freely falling, of course the increment of velocity will be less than 32.16 ft. The formulas above given may be made applicable by multiplying the value of g by the ratio between the height and length of the plane.

131. Initial Velocity of Falling Bodies.—We have been considering bodies falling from a state of rest, gravity being the only force that produced the motion. But a body may be thrown downward as well as dropped. In such a case, the effect of the throw must be added to the effect of gravity. It becomes an illustration of the first case under Composition of Forces (§ 80), the resultant being the sum of the components. If a body be thrown downward with an initial velocity of fifty feet per second, the formulas will become $v = gt + 50$; $s = \frac{1}{2}g\ (2t-1) + 50$; $S = \frac{1}{2}gt^2 + 50t$.

132. Ascending Bodies.—In the consideration of ascending bodies we have the direct opposite of the laws of falling bodies. When a body is thrown downward, gravity increases its velocity every second by the quantity g. When a body is thrown upward, gravity diminishes its velocity every second by the same quantity. Hence the time of its ascent will be found by dividing its initial velocity by g. *The initial velocity of a body that can rise against the force of gravity for a given number of seconds is the same as the final velocity of a body that has been falling for the same number of seconds.*

(*a.*) The spaces traversed and the velocities attained during successive seconds will be the same in the ascent, only reversed in order. If a body be shot upward with a velocity of 321.6 feet, it will rise for ten seconds, when it will fall for ten seconds. The tenth second of its ascent will correspond to the first of its descent, *i. e.*, the space traversed during these two seconds will be the same; the eighth second of the ascent will correspond to the third of its descent; the end of the eighth second of its ascent will correspond to the end of the second second of its descent.

133. Projectiles.—Every projectile is acted upon by three forces:

(1.) The impulsive force, whatever it may be.

(2.) The force of gravity.

(3.) The resistance of the air.

134. Random or Range.—*The horizontal distance from the starting-point of a projectile to where it strikes the ground is called its random or range.* In Fig. 30, the line GE represents the random of a projectile starting from F, and striking the ground at E.

135. Path of a Projectile.—The path of a projectile is a curve, the resultant of the three forces above mentioned. Suppose a ball to be thrown horizontally. Its impulsive force will give a uniform velocity, and may be represented by a horizontal line divided into equal parts, each part representing a space equal to the velocity. The force of gravity may be represented by a vertical line divided into unequal parts, representing the spaces 1, 3, 5, 7, etc., over which gravity would move it in successive seconds. Constructing the parallelograms of forces, we find that at the end of the first second the ball will be at A, at the end of the next second at B, at the end of the third at C, at the end of the fourth at D, etc. The resultant of these two forces is a curve called a parabola. It will be seen that, in a case like this, the range GE may be found by multiplying the velocity by the number of seconds it will take the body to fall from F to G. The resistance of the air modifies the nature of the curve somewhat.

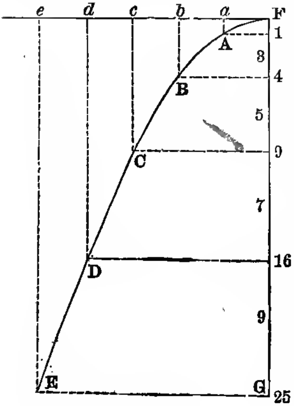


FIG. 30.

136. Time of a Projectile.—From the second law of motion, it follows that the ball shot horizontally will reach the level ground in the same time as if it had been dropped; that the ball shot obliquely upward from a horizontal plain will reach the ground in twice the time required to fall from the highest point reached. These statements may be easily verified by experiment.

EXERCISES.

1. What will be the velocity of a body after it has fallen 4 seconds?

Solution:

$$\begin{aligned} v &= gt. \\ v &= 32.16 \times 4. \\ v &= 128.64. \end{aligned}$$

Ans. 128.64 ft.

2. A body falls for several seconds; during one it passes over 530.64 feet; which one is it?

Solution:

$$\begin{aligned} s &= \tfrac{1}{2}g\,(2t-1). \\ 530.64 &= 16.08 \times (2t-1). \\ 33 &= 2t - 1. \\ 34 &= 2t. \\ 17 &= t. \end{aligned}$$

Ans. 17th second.

3. A body was projected vertically upward with a velocity = 96.48 feet; how high did it rise?

Solution:

$$\begin{aligned} v &= gt. \quad \text{(See § 132.)} \\ 96.48 &= 32.16t. \\ 3 &= t. \\ S &= \tfrac{1}{2}gt^2. \\ S &= 16.08 \times 9. \\ S &= 144.72. \end{aligned}$$

Ans. 144.72 ft.

4. How far will a body fall during the third second of its fall?

5. How far will a body fall in 10 seconds? *Ans.* 1608 ft.

6. How far in $\frac{1}{2}$ second? *Ans.* 4.02 ft.

7. How far will a body fall during the first one and a half seconds of its fall?

8. How far in $12\frac{1}{2}$ seconds?

9. A body passed over 787.92 feet during its fall; what was the time required? *Ans.* 7 sec.

10. What velocity did it finally obtain?

11. A body fell during $15\frac{1}{2}$ seconds; give its final velocity.

12. In an Attwood's machine the weights carried by the thread are $6\frac{1}{2}$ ounces each. The friction is equivalent to a weight of two ounces. When the "rider," which weighs one ounce, is in position, what will be its gain in velocity per second? *Ans.* 2.01 ft.

13. A stone is thrown horizontally from the top of a tower 257.28 ft. high with a velocity of 60 ft. a second. Where will it strike the ground? *Ans.* 240 ft. from the tower.

14. A body falls freely for 6 seconds. What is the space traversed during the last 2 seconds of its fall?

15. A body is thrown directly upward with a velocity of 80.4 ft. (*a*) What will be its velocity at the end of 3 seconds, and (*b*) in what direction will it be moving?

16. In Fig. 30, what is represented by the following lines: F1? Fa? Aa? Fc? Dd?

17. A body falls 357.28 ft. in 4 seconds. What was its initial velocity? *Ans.* 25 ft.

18. A ball thrown downward with a velocity of 35 ft. per second reaches the earth in $12\frac{1}{2}$ seconds. (*a*) How far has it moved, and (*b*) what is its final velocity?

19. (*a*) How long will a ball projected upward with a velocity of 3,216 ft. continue to rise? (*b*) What will be its velocity at the end of the fourth second? (*c*) At the end of the seventh?

20. A ball is shot from a gun with a horizontal velocity of 1,000 feet, at such an angle that the highest point in its flight = 257.28 feet. What is its random? *Ans.* 8000 ft.

21. A body was projected vertically downward with a velocity of 10 feet; it was 5 seconds falling. Required the entire space passed over. *Ans.* 452 ft.

22. Required the final velocity of the same body. *Ans.* 170.8 ft.

23. A body was 5 seconds rolling down an inclined plane and passed over 7 feet during the first second. (*a*) Give the entire space passed over, and (*b*) the final velocity.

24. A body rolling down an inclined plane has at the end of the first second a velocity of 20 feet; (*a*) what space would it pass over in 10 seconds? (*b*) If the height of the plane was 800 ft., what was its length? *Last Ans.* 1286.4 ft.

25. A body was projected vertically upward and rose 1302.48 feet; give (*a*) the time required for its ascent, (*b*) also the initial velocity.

26. A body projected vertically downward has at the end of the seventh second a velocity of 235.12 feet; how many feet will it have passed over during the first 4 seconds? *Ans.* 297.28 ft.

27. A body falls from a certain height; 3 seconds after it has started, another body falls from the height of 787.92 feet; from what height must the first fall if both are to reach the ground at the same instant? *Ans.* 1608 ft.

Recapitulation.—To be amplified by the pupil for review.

FALLING BODIES.

- **ACTED UPON BY A CONSTANT FORCE.**
- **RELATION OF WEIGHT TO VELOCITY.**
- **LAWS......**
  - ILLUSTRATIVE APPARATUS — Galileo's, Attwood's Experiments.
    - Results stated.
    - Results tabulated.
  - INCREMENT OF VELOCITY WITH FALL.
    - Unimpeded.
    - Impeded.
  - EXPRESSED IN.........
    - Mathematical symbols.
    - Ordinary language.
- **EFFECT OF INITIAL VELOCITY.**
- RELATIONS TO..........
  - Ascending bodies
  - Projectiles......
    - Influencing forces.
    - Random.
    - Path.
    - Time.

SECTION IV.

THE PENDULUM.

137. The Simple Pendulum.—A simple pendulum is conceived as *a single material particle supported by a line without weight, capable of oscillating about a fixed point.* Such a pendulum has a theoretical but not an actual existence, and has been conceived for the purpose of arriving at the laws of the compound pendulum.

138. The Compound Pendulum.—A compound or physical pendulum is *a weight so suspended as to be capable of oscillating about a fixed point.* The compound pendulum appears in many forms. The most common form consists of a steel rod, thin and flexible at the top, carrying at the bottom a heavy mass of metal known as the *bob.* The bob is sometimes spherical but generally lenticular, as this form is less subject to resistance from the air.

139. Motion of the Pendulum.—When the supporting thread or bar is vertical, the centre of gravity is in the lowest possible position, and the pendulum remains at rest, for the force of gravity tends to draw it downward producing pressure at the point of support, but no motion. But when the pendulum is drawn from its vertical position, the force of gravity, MG, is resolved (§ 91) into two components, one of which, MC, produces pressure at the point of support, while the other, MH, acts at right angles to it, producing motion. Gravity therefore draws it to a vertical position, when inertia carries it beyond until it is stopped and drawn back again by gravity. It thus swings to and fro in an arc, MNO.

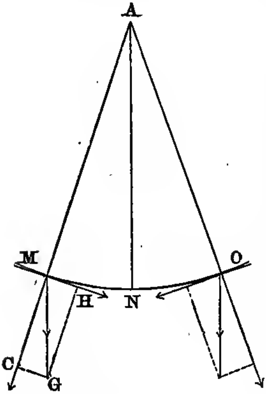


FIG. 31.

140. Definitions.—The motion from one extremity of this arc to the other is called a vibration or oscillation. The time occupied in moving over this arc is called the time of vibration or oscillation. The angle measured by this arc is called the amplitude of vibration. The trip from M to O is a vibration; the angle MAO is the amplitude of vibration.

141. Centre of Oscillation.—A short pendulum vibrates more rapidly than a long pendulum; this is a familiar fact. It is evident, then, that in every pendulum (not simple) the parts nearest the centre of suspension tend to move faster than those further away, and force them to move more rapidly than they otherwise would. On the other hand, the parts furthest from the centre of suspension tend to move more slowly than those nearer, and force these to retard their individual rates of motion. Between these there will be a particle moving, of its own accord, at the average rate of all. The accelerating tendency of the particles above it is compensated by the retarding tendency of the particles below it. *This molecule, therefore, will move as if it were vibrating alone, supported by a thread without weight.* It fulfills all the conditions of a simple pendulum. This point is called the *centre of oscillation.*

142. The Real Length of a Pendulum.—The laws of the simple pendulum are applicable to the compound pendulum if we consider the length of the latter to be the length of the equivalent simple pendulum, *i. e.*, *the distance between the centres of suspension and oscillation.* We, therefore, may say that the *real* length of a pendulum is the distance between the centre of suspension and the centre of oscillation. The real length is less than the apparent length except in the imaginary case of the simple pendulum.

143. First Law of the Pendulum.—*The vibrations of a given pendulum, at any given place, are isochronous, i. e.*, are performed in equal times, whether the arc be long or short. Each pupil should satisfy himself of the truth of this proposition, by the only true scientific method, experiment.

144. The Cycloidal Pendulum. — *The law above given is strictly true only when the pendu-*

lum vibrates in a cycloidal arc. A cycloid is the curve traced by a point in the circumference of a circle rolling along a straight line. The pendulum may be made to move in such an arc by suspending a small heavy ball by a thread between two cheeks upon which the thread winds as the pendulum vibrates. The cheeks must be the two halves of a cycloid; each cheek must have the same length as the thread. The path of the ball will be a cycloid, identical with that to which the cheeks belong.

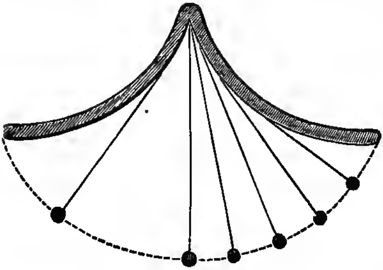


FIG. 32.

(*a.*) The cycloidal pendulum is of little practical use. If the amplitude of an ordinary pendulum does not exceed five degrees, the *circular arc*, thus described, will not vary much from the true cycloidal arc, and the pendulum will be practically isochronous. If from the centre of suspension, with radius equal to the length of the string, a circular arc be described, the two curves will sensibly coincide for at least five degrees. This is why the pendulums of "regulator" clocks have a small swing or amplitude.

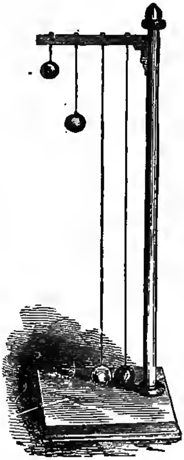


FIG. 33.

145. Second Law of the Pendulum.—*The time of vibration is independent of the weight or material of the pendulum,* depending only upon the length of the pendulum, and the intensity of the force of gravity at any given place.

(*a.*) Each pupil should try the experiment, *at home,* with balls of equal size but different weight. The investment of a little time and ingenuity in simple experiments will pay large dividends.

146. Third Law of the Pendulum.—The vibrations of pendulums of different lengths are performed in different times. *The lengths are directly proportional to the squares of the times of vibration, or inversely proportional to the squares of the numbers of vibrations in a given time.*

Note.—Be careful to distinguish clearly between the expressions "times of vibration" and "numbers of vibration." The greater the *time*, the less the *number*. You may easily verify by experiment the three laws already given for the pendulum.

147. The Second's Pendulum. At the equator, *the length of a second's pendulum, at the level of the sea, is 39 inches;* near the poles, 39.2; *in this latitude about 39.1 inches or 993.3 mm.* As such a pendulum would be inconveniently long, use is generally made of one one-fourth as long, which, consequently, vibrates half seconds. The length and time of vibration of this pendulum being thus known, the length of any other pendulum may be found when the time of vibration is given; or the time of vibration may be found when the length is given. The third law is applicable to such a problem.

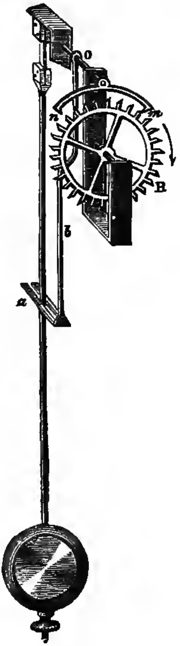


FIG. 34

148. Use of the Pendulum in Time-pieces.—The motion of a clock is due to the force of gravity acting upon the weights, or to the elasticity of the spring. But the weights have a tendency toward accelerated motion (falling bodies), while the spring would give an example of diminishing motion. Either defect would be fatal in a time-piece. Hence the properties of the pendulum set forth in the first and third laws are used to *regulate* this motion and make it available for the desired end. If the clock gains time, the pendulum is lengthened by lowering the bob; if it loses time, the pendulum is shortened by raising the bob.

149. Compensation Pendulums.—The expansion of metals by heat is a familiar fact. Hence the tendency of a clock to lose time in summer and to gain time in winter. One plan for counteracting this tendency is by the use of the "gridiron" pendulum which is made of two substances in such a manner that the downward expansion of one will be exactly compensated by the upward expansion of the other. In the figure, the heavy single lines represent steel rods, the effect of whose expansion will be to lower the bob. The light double lines represent brass rods, the effect of whose expansion will be to raise the bob. The steel rod to which the bob is directly attached passes easily through holes in the two horizontal bars which carry the brass uprights. As brass expands more than steel, for a given increase of temperature, it will be seen that these two expansions may be made to neutralize one another.

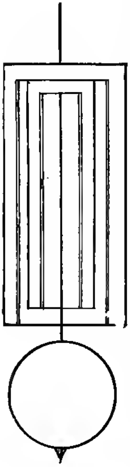


FIG. 35.

EXERCISES.

No.	INCHES.	NUMBER.	TIME.	No.	CM.	NUMBER.	TIME.
1	?	20 per min.	?	11	99.33	?	?
2	?	30 "	?	12	?	?	2 sec.
3	30	?	?	13	?	?	2 min.
4	16	?	?	14	24.83	?	?
5	?	?	¼ sec.	15	?	8 per sec.	?
6	?	?	¼ min.	16	397.32	?	?
7	39.37	? per min.	?	17	11.03	?	?
8	?	10 "	?	18	?	?	10 sec.
9	10	? per sec.	?	19	2483.25	?	?
10	?	1 per min.	?	20	?	?	4 sec.

21. How will the times of vibration of two pendulums compare, their lengths being 4 feet and 49 feet respectively? *Ans.* As 2 to 7.

22. Of two pendulums, one makes 70 vibrations a minute, the other 80 vibrations during the same time; how do their lengths compare? *Ans.* As 49 to 64.

23. If one pendulum is 4 times as long as another, what will be their relative times of vibration?

24. The length of a second's pendulum being 39.1 inches, what must be the length of a pendulum to vibrate in ⅕ second?

25. How long must a pendulum be to vibrate once in 8 seconds? In ⅛ second?

26. How long must a pendulum be to vibrate once in 3½ seconds?

27. Find the length of a pendulum that will vibrate 5 times in 4 seconds? *Ans.* 25.02 + inches.

28. A pendulum 5 feet long makes 400 vibrations during a certain time; how many vibrations will it make in the same time after the pendulum rod has expanded half an inch?

Recapitulation.—In this section we have considered the Simple Pendulum; the Compound Pendulum; the nature of the Motion of the Pendulum and its Cause; the meaning of the terms Vibration, Time of Vibration, Amplitude of Vibration; Centre of Oscillation; Real Length of a Pendulum; Laws and Formulas for the Pendulum; the Cycloidal Pendulum; the Second's Pendulum; the Use of the Pendulum in Clockwork; Compensation Pendulums.

SECTION V.

ENERGY.

150. Work.—In physical science, the word *work signifies the overcoming of resistance* of any kind. Whether this overcoming of resistance is pleasant or not does not enter into consideration here, all *play* being a species of *work.* The word is here used in this technical sense. When a force causes motion through space, it is said to do work. The product of the force acting and the space through which the body is moved measures the work done on that body. Work implies a change of position and is independent of the time taken to do it.

151. Energy.—*Energy is the power of doing work.* If one man can do more work than another, he has more energy. If a horse can do more work, in a given time, than a man, the horse has more energy than the man. If a steam-engine can do more work than a horse, it has more energy. If a moving cannon-ball can overcome a greater resistance than a base-ball it has more energy.

152. Elements of Work Measure.—Imagine a flight of stairs, each step having a rise of twelve inches. On the floor at the foot of the stairs are two weights, of one and ten pounds respectively. Lift the first weight to the top of the first step. How much work have you performed? Perhaps you will answer, one pound of work. Now place the second weight beside the first. How much work did you perform in so doing? Perhaps you will say ten times as much as before, or ten pounds. Now lift each of them another step, and then another, until they rest on the top of the tenth step. To lift the heavier weight the second, third, and subsequent times involved each as much work as to lift it the first foot, but you would hardly say that you had lifted a hundred pounds. Still it *is* sure that to place it on the tenth step required just ten times as much work as it did to place it on the first step, or just one hundred times as much work as it did to place the one pound weight on the first step. Moreover, it is evident that *the two elements of weight and height are necessarily to be considered* in measuring the work actually performed.

153. Units of Work; the Foot-pound.—It is often necessary to represent work numerically; hence the necessity for a unit of measurement. The unit commonly in use, for the present, in England and this country is the foot-pound. *A foot-pound is the amount of work required to raise one pound one foot high* against the force of gravity. The work required to raise one kilogram one meter high against the same force is called a *kilogram-meter.*

(*a.*) To get a numerical estimate of work, we multiply the number of weight units raised by the number of linear units in the vertical height through which the body is raised. A weight of 25 pounds, raised 3 feet, or one of 3 pounds raised 25 feet, represents 75 *foot-pounds.* A weight of 15 *Kg.* raised 10 *m.*, represents 150 *kilogram-meters.*

154. The Erg.—The C. G. S. (or absolute) unit of work is called the erg. *It is the work done in moving a free body one centimeter against a force of one dyne* (§ 69). The work of lifting one gram one centimeter against the force of gravity is 980 ergs. A foot-pound is about 13,560,000 ergs.

(*a.*) The definition of erg points out the fact that *work equals force multiplied by distance.*

155. Horse-Power.—The rate of doing work is called power. *A horse-power represents the ability to perform 550 foot-pounds in a second or 33,000 foot-pounds in a minute.* It equals 746×10^7 ergs per second.

(*a.*) An engine that can do 66,000 foot-pounds in a minute or 33,000 foot-pounds in half a minute is called a two horse-power engine. To compute the number of horse-powers represented by an engine at work, multiply the number of pounds raised by the number of feet, and divide the product by 550 times the number of seconds or 33,000 times the number of minutes required to do the work.

156. Relation of Velocity to Energy.—Any moving body can overcome resistance or perform work; it has energy. We must acquire the ability to measure this energy. In the first place, we may notice that the *direction* of the motion is unimportant. A body of given weight and velocity can, at any instant, do as much work when going in one direction as when going in another. This energy may be expended in penetrating an earth-bank, knocking down a wall or *lifting itself against the force of gravity.* Whatever be the work actually done, it is clear that the manner of expenditure does not change the amount of energy expended. *We may, therefore, find to what vertical height the given velocity would lift the body, and thus easily determine its energy in foot-pounds, kilogrammeters or dynes.*

157. An Easier Method.—If we can obtain the same result without the trouble of finding how high the given velocity could raise it, it is generally desirable to do so. Our vertical height is the whole space passed over by an ascending body (§ 132). We have given v to find S.

$$gt = v. \qquad t^2 = \frac{v^2}{g^2}.$$

$$t = \frac{v}{g}. \qquad S = \tfrac{1}{2}gt^2.$$

Substituting the above value of t^2, we have,

$$S = \tfrac{1}{2}g \times \frac{v^2}{g^2} = \frac{v^2}{2g}.$$

Energy $= wS$ (the weight into the height). Substituting our new value for S, we have the following important formula:

$$\textbf{Kinetic Energy} = \frac{wv^2}{2g}.$$

Since the weight of a body results from its mass and the force of gravity ($w = mg$),

$$\textbf{Kinetic Energy} = \tfrac{1}{2}mv^2.$$

(*a.*) If w be given in pounds; v, in feet per second and g in feet, the first formula will give the value of K. E. in foot-pounds.

(*b.*) If the gram be taken as the unit of mass and the centimeter per second as the unit of velocity, the second formula will give the value of K. E. in ergs.

158. Two Types of Energy.—There are two types of energy which may be designated as *energy of motion* and *energy of position*. With the first of these we are familiar. A falling weight or running stream possesses energy of motion; it is able to overcome resistance by reason of its weight and velocity. On the other hand, before the weight began to fall, while, as yet, it had no motion but was at rest, it had the power of doing work by reason of its elevated *position* with reference to the earth. When the water of the running stream was at rest in the lake among the hills it had a power of doing work, an energy, which was not possessed by the waters of the pond in the valley below. This energy or power results from its peculiar *position*. Energy of motion is called *kinetic* energy; energy of position is called *potential* energy.

159. Convertibility of Kinetic and Potential Energies.—We may at any moment convert kinetic energy into potential, or potential energy into kinetic. One is as real as the other, and when it exists at all, exists at the expense of a definite amount of the other. Imagine a ball thrown upward with a velocity of 64.32 feet. As it begins to rise it has a certain amount of kinetic energy. At the end of one second it has a velocity of only 32.16 ft. Consequently its kinetic energy has diminished. But it has risen 48.24 ft., and has already a considerable potential energy. All of this potential energy results from the kinetic energy which has disappeared. At the end of another second, the ball has no velocity; it has reached the turning-point and is at rest. Consequently, it has *no* kinetic energy. But the energy with which it began its flight has not been annihilated; it has been stored up in the ball at a height of 64.32 ft. as potential energy. If at this instant the ball be caught, all of the energy may be kept in store as potential energy. If now the ball be dropped, it begins to lose its potential and to gain kinetic energy. When it reaches the ground at the end of two seconds it has no potential energy, but *just as much* of the kinetic type as was given to it when it began to rise. This illustrates in a simple way the important principle, *the transformation or convertibility of energy without any change in its quantity.*

160. Energy a Constant Quantity.—In the case of the ball thrown upward, at the start, at the finish, or at any intermediate point of either its ascent or descent, the sum of the two types of energy is the same. It may be all kinetic, all potential, or partly both. In any case, *the sum of the two continually varying energies is constant.* Just as a man may have a hundred gold dollars, now in his hand, now in his pocket, now part in his hand and the rest in his pocket; changing a dollar at a time from hand to pocket or *vice versa,* the amount of money in his possession remains constant, viz., one hundred dollars.

161. Pendulum Illustration.—The pendulum affords a good and simple illustration of kinetic and potential energy, their equivalence and convertibility. When the pendulum hangs at rest in a vertical position, as P*a,* it has no energy at all. Considered as a mass of matter, separated from the earth, it certainly *has* potential energy; but considered as a pendulum, it has no energy. If the pendulum be drawn aside to *b,* we raise it through the space *ah;* that is, we do work, or spend kinetic energy upon it. The energy thus

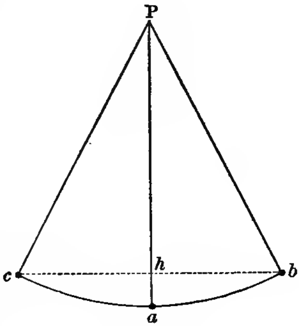


FIG. 36.

expended is now stored up as potential energy, ready to be reconverted into energy of the kinetic type, whenever we let it drop. As it falls the distance *ha*, in passing from *b* to *a*, this reconversion is gradually going on. When the pendulum reaches *a* its energy is all kinetic, and just equal to that spent in raising it from *a* to *b*. This kinetic energy now carries it on to *c*, lifting it again through the space *ah*. Its energy is again all potential just as it was at *b*. If we could free the pendulum from the resistances of the air and friction, the energy originally imparted to it would swing to and fro between the extremes of *all potential* and *all kinetic;* but at every instant, or at every point of the arc traversed, the total energy would be an unvarying quantity, always equal to the energy originally exerted in swinging it from *a* to *b*.

162. Indestructibility of Energy.—From the last paragraph it will be seen that, were it not for friction and the resistance of the air, the pendulum would vibrate forever; that the energy would be indestructible. Energy is withdrawn from the pendulum to overcome these impediments, but the energy thus withdrawn is not destroyed. What becomes of it will be seen when we come to study heat and other forms of energy, which result from the *motions* and *positions* of the molecules of matter. The truth is that *energy is as indestructible as matter.* For the present we must admit that a given amount of energy may disappear, and escape our search, but *it is only for the present.* We shall soon learn to recognize the fugitive even in disguise.

Note.—Physics may now be defined as the science of matter and energy.

Exercises.

1. How many horse-powers in an engine that will raise 8,250 lbs. 176 ft. in 4 minutes?

2. A ball weighing 192.96 pounds is rolled with a velocity of 100 feet a second. How much energy has it? *Ans.* 30000 foot-pounds.

3. A projectile weighing 50 Kg. is thrown obliquely upward with a velocity of 19.6 m. How much kinetic energy has it?

4. A ten-pound weight is thrown directly upward with a velocity of 225.12 ft. (*a.*) What will be its kinetic energy at the end of the third second of its ascent? (*b.*) At the end of the fourth second of its descent?

5. A body weighing 40 Kg. moves at the rate of 30 Km. per hour. Find its kinetic energy.

6. What is the horse-power of an engine that can raise 1,500 pounds 2,376 feet in 3 minutes? *Ans.* 36 H. P.

7. A cubic foot of water weighs about $62\frac{1}{2}$ pounds. What is the horse-power of an engine that can raise 300 cubic feet of water every minute from a mine 132 ft. deep?

8. A body weighing 100 pounds moves with a velocity of 20 miles per hour. Find its kinetic energy.

9. A weight of 3 tons is lifted 50 feet. (*a.*) How much work was done by the agent? (*b.*) If the work was done in a half-minute, what was the necessary horse-power of the agent?

10. How long will it take a two horse-power engine to raise 5 tons 100 feet?

11. How far can a two horse-power engine raise 5 tons in 30 sec.?

12. What is the horse-power of an engine that can do 1,650,000 foot-pounds of work in a minute?

13. What is the horse-power of an engine that can raise 2,376 pounds 1,000 feet in 2 minutes?

14. If a perfect sphere rest on a perfect, horizontal plane in a vacuum, there will be no resistance to a force tending to move it. How much work is necessary to give to such a sphere, under such circumstances, a velocity of 20 feet a second, if the sphere weighs 201 pounds? *Ans.* 1250 foot-pounds.

15. A railway car weighs 10 tons. From a state of rest it is moved 50 feet, when it is moving at the rate of 3 miles an hour. If the resistances from friction, etc., are 8 pounds per ton, how many foot-pounds of work have been expended upon the car? (First find the work done in overcoming friction, etc., through 50 ft. which is 50 foot-pounds × 10 × 8. To this add the work done in giving the car kinetic energy.)

Recapitulation.—In this section we have considered the meaning of Work and Energy; the Elements of Work-measure; the Unit of Work, as Foot-pound or Kilogram-meter; Horse-power; the relation between Velocity and Energy; a very convenient Formula for Energy; two Types of Energy, Kinetic and Potential; the mutual Convertibility of these two Types of Energy; the Sum of these two as a Constant Quantity; the Pendulum as an Illustration of this Convertibility and Constancy; the Indestructibility of Energy.

REVIEW QUESTIONS AND EXERCISES.

1. (*a.*) What is a molecule? (*b.*) An atom? (*c.*) Name the attractions pertaining to each.

2. (*a.*) Give an origiual illustration of a physical change. (*b.*) Of a chemical change.

3. (*a.*) What is the difference between general and characteristic properties of matter? (*b.*) Give an illustration of impenetrability, not mentioned in the book.

4. (*a.*) Upon what property do most of the characteristic properties of matter depend? (*b.*) Name five general and three characteristic properties of matter. (*c.*) Define inertia.

5. (*a.*) How does a solid differ from a liquid? (*b.*) From a gas? (*c.*) How does a gas differ from a vapor? (*d.*) What is a fluid?

6. (*a.*) Define dynamics. (*b.*) What is the difference between statics and kinetics? (*c.*) What is the gravity unit of force? (*d.*) The kinetic unit?

7. (*a.*) Give Newton's Laws of Motion. (*b.*) Explain the meaning of "parallelogram of forces." (*c.*) What is an equilibrant? (*d.*) Give the law of reflected motion.

8. (*a.*) What is the difference between gravity and gravitation? (*b.*) Give the law of gravitation. (*c.*) Of weight. (*d.*) What is meant by centre of gravity?

9. (*a.*) Describe the several kinds of equilibrium. (*b.*) Upon what does the stability of a body depend? (*c.*) Show how. (*d.*) What is the line of direction?

10. (*a.*) Why is it that a lead ball and a wooden ball will fall 100 feet in the same time? (*b.*) How did Galileo study the laws of falling bodies? (*c.*) Who was Galileo and when did he live? (*d.*) Define increment of velocity.

11. (*a.*) Give the laws of freely falling bodies. (*b.*) Express the same truths algebraically. (*c.*) What forces act upon a projectile? (*d.*) Define random.

12. (*a.*) What is a simple pendulum? (*b.*) A compound pendulum? (*c.*) What is the real length of a pendulum? (*d.*) How long must a pendulum be to vibrate once a minute? (*e.*) Once a second? (*f.*) What is the most important property of a pendulum?

13. Two forces of 6 and 8 pounds respectively act at right angles to each other. Find the direction and intensity of their equilibrant.

14. (*a.*) Define energy. (*b.*) Foot-pound. (*c.*) Horse-power. (*d.*) Give the rule for calculating horse-power.

15. (*a.*) What is a kilogram-meter? (*b.*) Give the formula for the calculation of kinetic energy from weight and velocity. (*c.*) Deduce the same.

16. (*a.*) State fully and clearly the difference between kinetic and potential energy. (*b.*) Illustrate the same by the pendulum.

17. (*a.*) What is the object of experiments in the study of physics? (*b.*) What is the metric unit of weight? (*c.*) How is it obtained?

18. Three inelastic balls weighing 5, 7 and 8 pounds, lie in the same straight line. The first strikes the second with a velocity of 60 feet per second; the first and second together strike the third. What will be the velocity of the third? *Ans.* 15 ft.

19. To how many F. P. S. units of force is the weight of 9 lb. equal?

20. To how many C. G. S. units of force is the weight of 9 *Kg.* equal?

21. How many ergs will represent the kinetic energy of a ball weighing 50 grams and moving at the rate of 60 *cm.* a second?

Ans. 90,000.

22. Determine the amount of work performed in discharging a 30 gram bullet with a velocity of 400 *m.* per second.

Ans. 24×10^9 ergs.

CHAPTER III.

SIMPLE MACHINES.

SECTION I.

PRINCIPLES OF MACHINERY.—THE LEVER.

163. What is a Machine?—*A machine is a contrivance by means of which the force can be applied to the resistance more advantageously.* Its general office is to effect a transformation in the intensities of energies, so that an energy of small intensity, acting through a considerable distance, may be made to reappear as an energy of considerable intensity, acting through a small distance, or *vice versa.*

164. A Machine cannot Create Energy.—No machine can create or increase energy. In fact, the use of a machine is accompanied by a waste of power which is needed to overcome the resistances of friction, the air, etc. A part of the energy exerted must therefore be used upon the machine itself, thus diminishing the amount that can be transmitted or utilized for doing the work in hand.

165.—A Common Error.—A clear understanding of this fact is very important. *There is a very common* *erroneous notion that, in some way or other, a machine performs work* of itself—that it is *a source of power.* It were as reasonable to imagine that a bank is a source of real money. The bank can pay out no more than it receives; neither can a machine. A man may go to the bank with a ten-dollar gold piece, and get for it ten one-dollar gold pieces. In like manner, he may go to a machine with an ability of moving ten pounds one foot in a given time, and get for it the ability of moving one pound ten feet in the same time. He may exchange what he has for what he prefers; but, in the case of the bank and of the machine alike, the equivalent must be paid, and generally a commission for the transfer.

166. Of what Use are Machines?—Some of the many advantages resulting from the use of machines are:

(1.) It enables us to exchange intensity for a velocity otherwise unattainable, as in the case of the sewing machine or spinning wheel.

(2.) It enables us to exchange velocity for an intensity of power otherwise unattainable, as in the case of lifting a large stone with a crow-bar or pulleys.

(3.) It enables us to change the direction of our force, as in the case of hoisting a flag on a flag-staff. It would be inconvenient to climb the pole and then draw up the flag.

(4.) It enables us to employ other forces than our own, as the strength of animals, the forces of wind, water, steam, etc.

167. General Laws of Machines.—The work to be done by a machine is generally called the weight or load. The force applied is called the power. The work of the power (*e. g.*, foot-pounds) is always equal to the work of the load, the work expended in the machine itself being disregarded. The following laws are, therefore, applicable to machines of every kind:

(1.) *What is gained in intensity of power is lost in time, velocity, or distance;* and what is gained in time, velocity, or distance is lost in intensity of power.

(2.) *The power multiplied by the distance through which it moves, equals the weight multiplied by the distance through which it moves.*

(3.) *The power multiplied by its velocity, equals the weight multiplied by its velocity.*

168. What is a Lever?—*A lever is an inflexible bar capable of being freely moved about a fixed point or line, called the fulcrum.*

In every lever, three points are to be considered, viz.: the fulcrum and the points of application for the power and the weight. Every lever is said to have two arms. The power-arm is the perpendicular distance from the fulcrum to the line in which the power acts; the weight-arm is the perpendicular distance from the fulcrum to the line in which the weight acts. If the arms are not in the same straight line, the lever is called a bent lever.

169. Classes of Levers.—There are three classes of levers, depending upon the relative positions of the power, weight, and fulcrum.

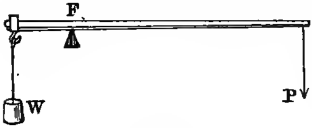


FIG. 37.

(1.) If the fulcrum is between the power and weight (P. F. W.), the lever is of the first class (Fig. 37); *e. g.*, crowbar, balance, steelyard, scissors, pincers.

(2.) If the weight is between the power and the fulcrum (P. W. F.), the lever is of the second class (Fig. 38); *e. g.*, cork-squeezer, nut-cracker, wheel-barrow.

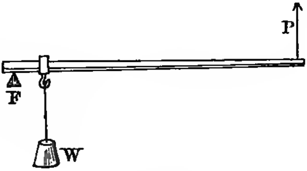


FIG. 38.

(3.) If the power is between the weight and the fulcrum (W. P. F.), the lever is of the third class (Fig. 39); *e. g.*, fire-tongs, sheep-shears, human fore-arm.

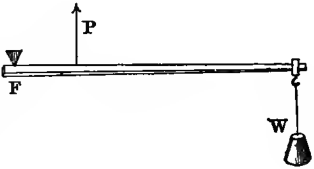


FIG. 39.

170. Static Laws of the Lever.—It will be clearly seen or may be geometrically shown that the ratio between the arms of the lever will be the same as the ratio between the velocities of the power and the weight, and the same as the ratio between the distances moved by the power and the weight. If the power-arm be twice as long as the weight-arm, the power will move twice as fast and twice as far as the weight does. The general laws of machines may therefore be adapted to the lever as follows:

$$\mathrm{P} \times \text{power-arm} = \mathrm{W} \times \text{weight-arm, or } \mathrm{P} \times \overline{\mathrm{PF}} = \mathrm{W} \times \overline{\mathrm{WF}}.$$

$$\therefore P : W :: \overline{WF} : \overline{PF}.$$

(1.) In the case of the lever, the power and weight are inversely proportional to the corresponding arms of the lever; or, (2.) The power multiplied by the power-arm equals the weight multiplied by the weight-arm ; or,

(3.) *A given power will support a weight as many times as great as itself, as the power-arm is times as long as the weight-arm.*

Note.—A static law expresses the relation between the power and weight when the machine is in equilibrium. In order that there be *motion*, one of the products mentioned in the law above must be greater than the other. The lever itself must be in equilibrium before the power and weight are applied. It is to be noticed that when we speak of the power multiplied by the power-arm, we refer to the abstract numbers representing the power and power-arm. We cannot multiply pounds by feet, but we can multiply the number of pounds by the number of feet.

171. The Moment of a Force.—The moment of a force acting about a given point, as the fulcrum of a lever, is *the product of the numbers representing respectively the magnitude of the force and the perpendicular distance between the given point and the line of the force.* In the case of the lever represented in Fig. 37, the weight-arm is 8 *mm.* and the power-arm is 30 *mm.* Suppose that the power is 4 grams, and let the weight be represented by x. Then the moment of the force acting on the power-arm will be represented by (4 × 30 =) 120, and the moment of the force acting on the weight-arm by $8x$.

172. Moments Applied to the Lever.—We sometimes have several forces acting upon one or both arms of a lever, in the same or in opposite directions.

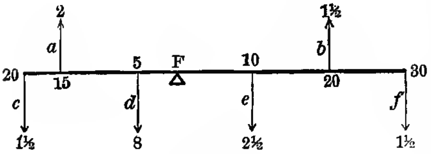


FIG. 40.

Under such circumstances, the lever will be in equilibrium, when the sum of the moments of the forces tending to turn the lever in one direction is equal to the sum of the moments of the forces tending to turn the lever in the other direction. Representing *the moments* of the several forces acting upon the lever represented in the figure by their respective letters and numerical values,

$$\begin{array}{r|l} b+c+d=a+e+f & 30+30+40=30+25+45. \\ \text{or, } c+d-a=e+f-b & 30+40-30=25+45-30. \end{array}$$

173. Bent Levers.—When the lever is not a straight bar, or *when, for any reason, the power and weight do not act parallel to each other,* it becomes necessary to distinguish between the *real* and *apparent* arms of the lever. This will be easily done, if you are familiar with the definition of the arms of a lever, given in § 168. In Fig. 41, we have represented a very simple kind of bent lever, which is sufficiently explained by the engraving. In Fig. 42, we have a representation of a curved rod lever, W′P′, at the ends of which two forces, not parallel, are acting. Our definition of the arms of the lever, already learned, removes every difficulty arising from the form of the lever, or the direction in which the forces act. The arms are not FP′ and FW′, but FP and FW.

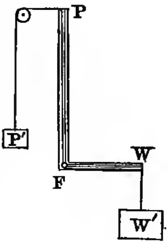


FIG. 41.

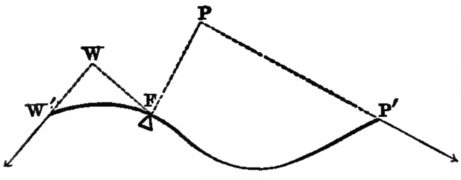


FIG. 42.

174. Load between Two Supports.—*If a beam rest on two supports, and carry a load between them, the beam may be considered a lever of the second class.* The part carried by either support may be found by considering it as the power, and the other support as the fulcrum. (Fig. 43.)

FIG. 43.

175. The Balance.—*The balance is essentially a lever of the first class, having equal arms.* Its use is to determine the relative weights of bodies. Its action depends upon the equality of moments explained in § 171 and § 172. The lever itself is called the beam. From the ends of the beam are suspended two pans, one to carry the weights used, the other to carry the article to be weighed. An index needle, or pointer, is often attached to the beam, and indicates equilibrium, by pointing to the zero of a graduated scale, carried by a fixed support.

(*a.*) That the balance may be accurate, the arms must be of the same length. To make these arms exactly equal is far from an easy task. That the balance may be delicate, it must turn upon its axis with little friction, the axis of support must be a very little above the centre of gravity, the arms must be of considerable length, and the beam must be light. Balances are made so delicate that they may be turned by less than a thousandth of a grain. The supporting edge of the axis is made very sharp and hard, and rests upon two supports, generally made of agate or polished steel. A really good balance is an expensive piece of apparatus.

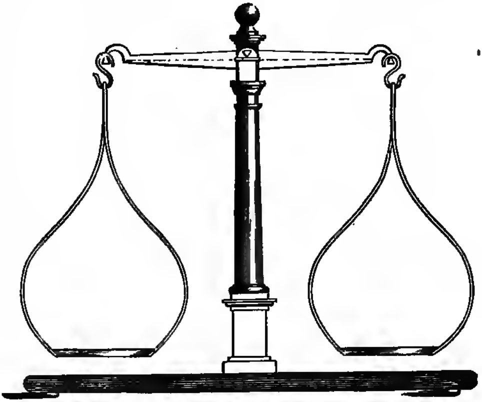


FIG. 44.

176. False Balances.—*False balances (levers of the first kind with unequal arms) are sometimes used by dishonest dealers.* When buying, they place the goods on the shorter arm; when selling, on the longer. The cheat may be exposed by changing the goods and weights to the opposite sides of the balance. The true weight may be found by weighing the article first on one side and then on the other, and taking the *geometrical* mean of the two false weights; that is, by finding the square-root of the product of the two false weights.

177. Double Weighing.—In another way the true weight of a body may be found with a false balance. The article to be weighed is placed in one pan, and a counterweight, as of shot or sand, placed in the other pan until equilibrium is produced. The article is then removed, and known weights placed in the pan until equilibrium is again produced. The sum of these weights will be the true weight of the given article.

178. Compound Lever.—Sometimes it is not convenient to use a lever sufficiently long to make a given power support a given weight. A combination of levers called a compound lever may then be used. Hay-scales may be mentioned as a familiar illustration of the compound lever. In this case we have the following:

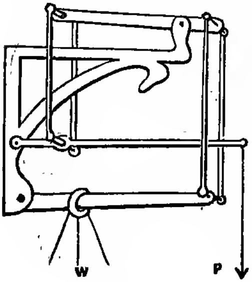


FIG. 45.

Statical Law.—*The continued product of the power and the lengths of the alternate arms, beginning with the power-arm, equals the continued product of the weight and the lengths of the alternate arms beginning with the weight-arm.*

EXERCISES.

No.	Power-Arm.	Weight-Arm.	Power.	Weight.	No.	Power-Arm.	Weight-Arm.	Power.	Weight.	Lever.	
										Length.	Class.
1	4 ft.	2 ft.	50 lbs.	?	11	5 ft.	?	50 lbs.	25 lbs.	10 ft.	?
2	3 ft.	9 ft.	?	75 lbs.	12	?	?	15 oz.	45 oz.	12 in.	2
3	10 ft.	4 ft.	14 lbs.	?	13	?	50 cm.	1 Kg.	4 Kg.	?	2
4	60 in.	?	2 lbs.	30 lbs.	14	16⅔ cm.	?	12 oz.	2 oz.	?	3
5	?	18 cm.	27 Kg.	9 Kg.	15	3 ft.	5 ft.	10 lbs.	?	?	1
6	14 ft.	?	45 oz.	63 oz.	16	39.37 in.	50 cm.	?	20 Kg.	?	1
7	40 cm.	56 cm.	21 g.	?	17	?	16 ft.	14 lbs.	3½ lbs.	16 ft.	?
8	18 in.	21 in.	?	24 oz.	18	?	2 ft.	30 lbs.	?	10 ft.	1
9	26 cm.	?	11 Dg.	13 Dg.	19	?	2 ft.	30 lbs.	?	10 ft.	2
10	?	1 ft.	50 lbs.	2500 lbs.	20	2 ft.	?	30 lbs.	?	10 ft.	3

Note to the Pupil.—If any of these problems be obscure to you, remember that it will *pay* to draw an accurate figure or diagram of the machine representing the several powers and weights in position. See Fig. 40.

21. If a power of 50 pounds acting upon any kind of machine, move 15 feet, (*a*) how far can it move a weight of 250 pounds? (*b*.) How great a load can it move 75 feet?

22. If a power of 100 pounds acting upon a machine, moves with a velocity of 10 feet per second, (*a*) to how great a load can it give a velocity 125 feet per second? (*b*.) With what velocity can it move a load of 200 pounds?

23. A lever is 10 feet long; F in the middle; a power of 50 pounds is applied at one end; (*a*) how great a load at the other end can it support? (*b*.) How great a load can it lift?

Ans. to (*b*.): Anything less than 50 lbs.

24. The power-arm of a lever is 10 feet; the weight-arm is 5 feet. (*a*.) How long will the lever be if it is of the first class? (*b*.) If it is of the second? (*c*.) If it is of the third class?

25. A bar 12 feet long is to be used as a lever, keeping the weight 3 feet from the fulcrum. (*a*.) What class or classes of levers may it represent? (*b*.) What weight can a power of 10 pounds support in each case?

26. Length of lever = 10 feet. Four feet from the fulcrum and at the end of that arm is a weight of 40 pounds; two feet from the fulcrum on the same side, is a weight of 1,000 pounds. What force at the other end will counterbalance both weights? *Ans.* 360 lb.

27. At the opposite ends of a lever 20 feet long, two forces are acting whose sum = 1,200 pounds. The lengths of the lever arms are as 2 to 3; what are the two forces when the lever is in equilibrium?

28. Length of lever = 8 feet, F in the centre. A force of 10 pounds acts at one end, one foot from it another of 100 pounds. Three feet from the other end is a force of 100 pounds. Direction of all forces, downward. Where must a downward force of 80 pounds be applied to balance the lever? *Ans.* 3 ft. from F.

29. Length of lever *ab* = $6\frac{1}{4}$ feet; fulcrum at *c*; a downward force of 60 pounds acts at *a*; one of 75 pounds at a point *d* between *a* and *c*, $2\frac{3}{4}$ feet from the fulcrum; required the amount of equilibrating force acting at *b*, the distance between *b* and *c* being $\frac{3}{4}$ feet.

30. On a lever *ab*, a downward force of 40 pounds acts at *a*, 10 feet from fulcrum *c*; on same side and $6\frac{1}{2}$ feet from *c*, an upward force, *d*, acts, amounting to 56 pounds; distance *bc* = 3 feet: a downward force of 96 pounds acts at *b*. (*a*.) Where must a fourth force of 28 pounds be applied to balance the lever, and (*b*) what direction must it have?

31. A beam 18 feet long is supported at both ends; a weight of 1 ton is suspended 3 feet from one end, and a weight of 14 cwt..

8 feet from the other end. Give the pressure on each point of support. *Ans.* $2288\frac{8}{9}$ lb. at one end.

32. Length of lever = 3 feet; where must the fulcrum be placed so that a weight of 200 lbs. at one end shall be balanced by 40 lbs. at the other end?

33. In one pan of a false balance, a roll of butter weighs 1 lb. 9 oz.; in the other, 2 lbs. 4 oz. Find the true weight.

34. A and B at opposite ends of a bar 6 ft. long carry a weight of 300 lbs. suspended between them. A's strength being twice as great as B's, where should the weight be hung?

35. A and B carry a quarter of beef weighing 450 pounds on a rod between them. A's strength is $1\frac{1}{4}$ that of B's; the rod is 8 feet long; where should the beef be suspended?

36. Length of lever = 16 feet; weight at one end, 100 pounds: what power applied at other end, $3\frac{1}{2}$ feet from the fulcrum, is required to *move* the weight?

37. A power of 50 lbs. acts upon the long arm of a lever of the first class; the arms of this lever are 5 and 40 inches respectively. The other end acts upon the long arm of a lever of the second class; the arms of this lever are 6 and 33 inches respectively. (*a.*) Figure the machine. (*b.*) Find the weight that may be thus supported. (*c.*) What power will support a weight of 4,400 kilograms?

Recapitulation.—To be amplified by the pupil for review.

- MACHINES.
  - **DEFINITION.**
  - **RELATION TO ENERGY.**
  - **USE.**
  - **GENERAL LAWS.**
  - **THE LEVER.** . . .
    - DEFINITION.
    - ARMS.
    - STATIC LAWS.
    - CLASSES.
      - 1. BALANCE.
        - True.
        - False.
          - *Double Weighing.*
      - 2. LOAD BETWEEN TWO SUPPORTS.
      - 3.
    - BENT.
    - COMPOUND.
  - **MOMENTS OF FORCES.**

SECTION II.

THE WHEEL AND AXLE AND WHEEL-WORK.

179. The Wheel and Axle.—The wheel and axle consists of *a wheel united to a cylinder in such a way that they may revolve together about a common axis.* It is a modified lever of the first class.

180. Advantages of the Wheel and Axle.—The ordinary range of action of a lever of the first class is very small. In order to raise the load higher than the vertical distance through which the weight end of the lever passes, it is necessary to support the load and re-adjust the fulcrum. This occasions an intermittent action and loss of time, difficulties which are obviated by using the wheel and axle.

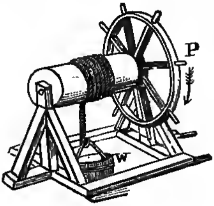


FIG. 46.

181. A Modified Lever.—Considered as a lever of the first class, the fulcrum is at the common axis, while the arms of the lever are the radii of the wheel and of the axle. If $a\,c$, the radius of the wheel, be used as the power-arm, velocity or time is exchanged for intensity of power. This is the usual arrangement. If bc, the radius of the axle, be used as the power-

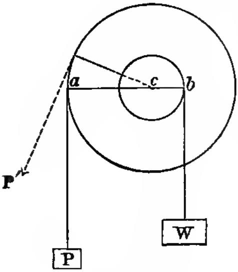


FIG. 47.

arm, there will be an exchange of intensity of power for velocity or time. In treating of the wheel and axle, unless otherwise specified, reference is made to the former or usual arrangement.

182. Formulas for Wheel and Axle.—The law and formula for the lever apply here:

$$P : W :: \overline{WF} : \overline{PF}, \quad \text{or,} \quad P : W :: r : R,$$

the radii of the wheel and of the axle respectively being represented by R and r. But it is a geometrical truth that in any two circles, the ratio of their radii is the same as the ratio of their diameters or circumferences. Hence these ratios may be substituted for the ratio between the radii of the wheel and axle; or,

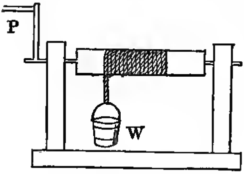


FIG. 48.

$$P : W :: r : R.$$
$$P : W :: d : D.$$
$$P : W :: c : C.$$

183. Law of Wheel and Axle.—*The power multiplied by the radius, diameter or circumference of the wheel equals the weight multiplied by the corresponding dimension of the axle.*

Note.—If the radius of the axle be made the power-arm, the formulas will be as follows:

$$P : W :: \overline{WF} : \overline{PF}, \quad \text{or,} \quad P : W :: D : d.$$

184. Various Forms of Wheel and Axle.—The wheel and axle appears in various forms. It is not necessary that an entire wheel be present, a single spoke or radius being sufficient for the application of the power, as in the case of the windlass (Fig. 48) or capstan (Fig. 49). In all such cases, the radius being given, the diameter or circumference of the wheel may be easily computed. In one of the most common forms, the power is applied by means of a rope wound around the circumference of the wheel. When this rope is unwound by the action of the power, another rope is wound up by the axle, and the weight thus raised.

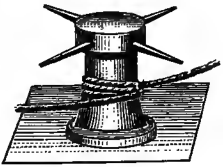


FIG. 49.

185. Wheel-work.—Another method of securing a great difference in the intensities of balancing forces, is to use a combination of wheels and axles of moderate size. Such a combination constitutes a train. The wheel that imparts the motion is called the *driver ;* that which receives it, the *follower.* An axle with teeth upon it is called a *pinion.* The teeth or cogs of a pinion are called *leaves.*

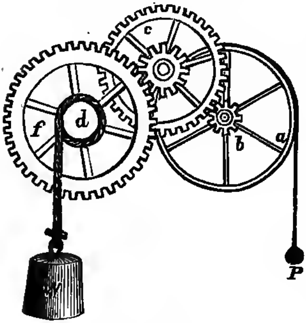


FIG. 50.

186. Law of Wheel-work.—A train of wheel-work is clearly analogous to a compound lever; the statical law, given in § 178, may be adapted to our present purposes as follows: *The continued product of the power and the radii of the wheels equals the continued product of the weight and the radii of the axles.*

187. Another Law of Wheel-work.—By examination of Fig. 50, it will be seen that while the axle *d* revolves once, the wheel and pinion *c* will revolve as many times as the number of leaves borne by *c* is contained times in the number of teeth borne by *f*. In like manner, while the wheel *c* revolves once, the wheel and pinion *b* will revolve as many times as the number of leaves borne by *b* is contained times in the number of teeth borne by *c*. By combination of these results, we see that while *d* revolves once, *b* will have as many revolutions as the product of the number of leaves is contained times in the product of the number of teeth. From this it follows that the ratio between the continued product of the circumference (diameter or radius) of *d* into the number of leaves on the several pinions and the continued product of the corresponding dimension of *b* into the number of teeth on the several wheels will be the ratio between the distances or velocities of *W* and *P*, and therefore the ratio between the intensities of balancing weights or forces.

In short, the continued product of the power, the circumference of *a* and the number of teeth on *c* and *f* equals the continued product of the weight, the circumference of *d* and the number of leaves on the pinions *c* and *b*.

188. Example.—Suppose the circumferences of *a* and *d* to be 60 *mm.* and 15 *mm.* respectively; that *b* has 9 leaves; *c* has 36 teeth and 13 leaves; *f* has 40 teeth. Then will

$$\mathrm{P} \times 60 \times 36 \times 40 = \mathrm{W} \times 15 \times 13 \times 9.$$

189. Ways of Connecting Wheels.—Wheels may be connected in three ways:

(1.) By the friction of their circumferences.

(2.) By bands or belts.

(3.) By teeth or cogs.

The third of these methods has been already considered.

190. Uses of the First Two Ways.—The first method is used where no great resistance is to be overcome, but where evenness of motion and freedom from noise are chiefly desired. It is illustrated in some sewing-machines. The second method is used when the follower is to be at some distance from the driver. The friction of the belt upon the wheels must be greater than the resistance to be overcome. It is illustrated in most sewing-machines, and in the spinning-wheel.

191. Relation of Power to Weight Determined.—The follower will revolve as many times as fast as the driver, as its circumference is contained times in that of the driver. The problem of finding the distances passed over in a given time by the power and weight, and thence the relative intensities of the power and the weight, thus becomes an easy one.

EXERCISES.—*The Wheel and Axle.*

Remark.—The circumference of a circle is 3.1416 times greater than its diameter.

No. of Problem.	Power.	Weight.	DIMENSIONS.					
			R	*D*	*C*	*r*	*d*	*c*
1	25 lbs.	?	?	......	20 ft.	......	......	4 ft.
2	?	750 Kg.	.....	......	12.50 m.	.....	?	50 cm.
3	23 lbs.	230 lbs.	.....	15 ft.	....	......	?	?
4	9 Kg.	153 Kg.	.....	......	?	......	.....	17 cm.
5	1341 Kg.	?	.....	......	628.32 cm.	......	20 cm.	......
6	195 lbs.	?	.....	......	25 in.	......	......	15 in.
7	?	80 Kg.	1 m.	......	....	4 cm.	......	......
8	3 lbs.	48 lbs.	.....	16 in.	....	?	?	......
9	2 lbs.	40 lbs.	3 dm.	......	... .	?	?	......
10	49 lbs.	?	.....	16 in.	....	......	7 in.	... ..
11	18 oz.	?	.....	......	78.74 in.	......	......	10 cm.

12. The pilot-wheel of a boat is 3 feet in diameter; the axle, 6 inches. The resistance of the rudder is 180 pounds. What power applied to the wheel will move the rudder?

13. Four men are hoisting an anchor of 1 ton weight; the barrel of the capstan is 8 inches in diameter. The circle described by the handspikes is 6 feet 8 inches in diameter. How great a pressure must each of the men exert?

14. With a capstan, four men are raising a 1000 pound anchor. The barrel of the capstan is a foot in diameter; the handspikes used are 5 feet long; friction equals 10 *per cent* of the weight. How much force must each man exert to raise the anchor?

15. The circumference of a wheel is 8 ft.; that of its axle, 16 inches. The weight, including friction, is 85 pounds; how great a power will be required to raise it?

16. A power of 70 pounds, on a wheel whose diameter is 10 feet, balances 300 pounds on the axle. Give the diameter of the axle.

17. An axle 10 inches in diameter, fitted with a winch 18 inches long, is used to draw water from a well. (*a.*) How great a power will it require to raise a cubic foot of water which weighs 62½ lbs.? (*b.*) How much to raise 20 litres of water?

18. A capstan whose barrel has a diameter of 14 inches is worked by two handspikes, each 7 feet long. At the end of each handspike a man pushes with a force of 30 pounds; 2 feet from the end of each handspike, a man pushes with a force of 40 pounds; required the effect produced by the four men.

19. How long will it take a horse working at the end of a bar 7 feet long, the other end being in a capstan which has a barrel of 14 inches in diameter, to pull a house through 5 miles of streets, if the horse walk at the rate of 2½ miles an hour?

Recapitulation.—To be amplified by the pupil for review.

WHEEL AND AXLE.
- DEFINITIONS.
- ADVANTAGES.
- RELATION TO THE LEVER.
- FORMULAS AND LAWS.
- FORMS.
- WHEEL WORK.
  - DRIVER.
  - FOLLOWER.
  - LAWS.
  - CONNECTIONS.
    - MODES.
    - USES.
  - RELATION OF P TO W

SECTION III.

THE PULLEY AND THE INCLINED PLANE.

192. What is a Pulley?—*A pulley consists of a wheel turning upon an axis and having a cord passing over its grooved circumference.* The frame supporting the axis of the wheel is called the block.

193. A Fixed Pulley.—The advantages arising from the use of a pulley depend upon the *uniform tension* of the cord. If a cord be passed over a pulley fixed to the ceiling, a weight being at one end and the hand applied at the other, the tension of the cord will be uniform, and the hand will have to exert a force equal to the weight of the load. If the weight be moved, the hand and weight will move equal distances. It is evident, then, that the *fixed pulley affords no increase of power, but only change of direction.*

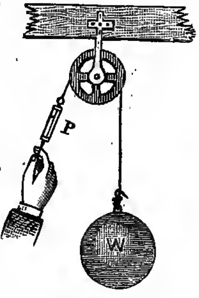


FIG. 51.

194. A Movable Pulley.—If one end of the cord be fastened to the ceiling, the load suspended from the pulley, and the other end of the cord drawn up by the hand, it will be evident, from the equal tension of the cord, that the fixed support carries half the load and the hand the other half. It is also evident that to raise the weight one foot the hand must pull up two feet of the cord; that is to

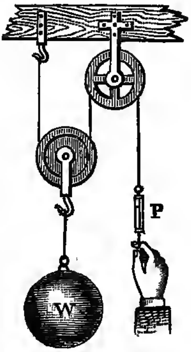


FIG. 52.

say, *each section* of the cord carrying the weight must be shortened one foot. Thus the hand, by lifting 50 pounds two feet, is able to raise 100 pounds one foot. It is to be noticed that we have here no creation or increase of energy, *working power,* but that we do secure an important transformation of velocity into intensity.

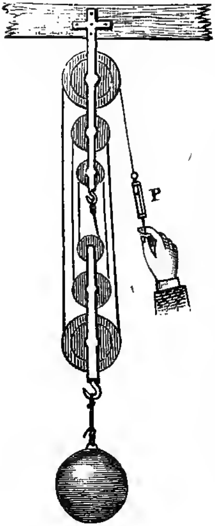


FIG. 53.

195. A Combination of Pulleys.—By the use of several fixed and movable pulleys in blocks, the number of parts of the cord supporting the movable block may be increased at pleasure. In all such cases, the tension of the cord will be uniform, and the part of the cord to which the power is applied, will carry only a *part of the load.* The value of this part of the load depends upon the number of sections into which the movable pulley divides the cord.

196. Law of the Pulley.—*With a pulley having a continuous cord, a given power will support a weight as many times as great as itself as there are parts of the cord supporting the movable block.*

FIG. 54.

197. Concerning the Number of Parts of the Cord.—By observing the several figures of pulleys in this section, it will be seen that when the fixed end of the cord is attached to the *fixed* block, the number of parts of the cord supporting the weight is twice the number of movable pulleys used; that when the fixed end of the cord is attached to the movable block the number of parts of the cord is one more than twice the number of movable pulleys used.

198. What is an Inclined Plane?—*The inclined plane is a smooth, hard, inflexible surface inclined so as to make an oblique angle with the direction of the force to be overcome.* In most cases it is a plane surface inclined to the horizon at an acute angle, and is used to aid in the performance of work against the force of gravity.

199. Resolution of the Force of Gravity.—When a weight is placed upon an inclined plane, the force of gravity tends to draw it vertically downward. This force may be resolved into two forces (§ 91), one acting perpendicularly to the plane, producing pressure completely resisted by the plane, the other component acting opposite to the direction of the power which it is to counterbalance. The first component shows how much pressure is exerted upon the plane; the other shows what force must be exerted to maintain equilibrium. The value of the second component will, plainly, vary with the direction of the power.

200. Three Cases.—In the use of an inclined plane, three cases may arise:

(1.) Where the power acts in a direction parallel to the length of the plane.

(2.) Where the power acts in a direction parallel to the base of the plane (generally horizontal).

(3.) Where the power acts in a direction parallel to neither the length nor the base of the plane.

201. The First Case.—In the accompanying figure, let

LM represent a plane inclined to the horizontal line *LN*. Let *A* represent a ball weighing 20 *Kg*. The problem is to find what force acting in the direction *LM* will hold it in equilibrium. The weight of the body *A* is a downward force of 20 *Kg*., which may be graphically represented (§ 81) by the vertical line *AC*, 20 *mm*. in length. Any other convenient unit of length might be used, but the scale of 1 *mm*. to the *Kg*. being adopted, it must be maintained throughout the problem. The force represented by *AC* is resolved into two components represented by *AD*, perpendicular to *LM*, and by *AB*, parallel to it. The former component measures the pressure to be resisted by the plane; the latter component measures the force with which the ball is drawn towards *L*. This second component is to be balanced by the equal and opposite force *AB′*, the equilibrant of *AB*. It may be proved geometrically that

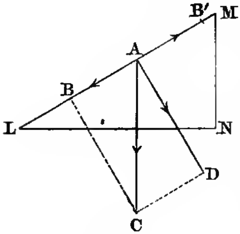


FIG. 55.

AB : AC :: MN : ML. (*Olney's Geometry*, Art. 341.)

Careful construction and measurement will give the same result. But *AB*, or rather its equal *AB′*, represents the power; *AC* represents the weight; *MN* represents the height; and *ML*, the length of the plane. Therefore,

$$P : W :: h : l, \quad \text{or,} \quad P = \text{the } \frac{h}{l} \text{ part of } W.$$

202. Law for the First Case.—In the figure above, ML is twice the length of MN, and AC is twice the length of AB or AB′. This indicates that a force of 10 *Kg*. acting in the direction LM would hold the ball in equilibrium. This result may be easily verified by experiment. We may therefore establish the following law: *When a given power acts parallel to the plane, it will support a weight as many times as great as itself as the length of the plane is times as great as its vertical height.*

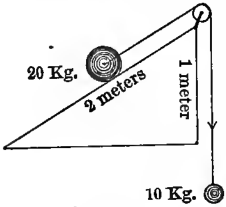


FIG. 56.

203. Law for the Second Case.—By resolving the force of gravity, or by experiment, the following law may be established: *When a given power acts parallel to the base, it will support a weight as many times as great as itself as the horizontal base of the plane is times as great as its vertical height.*

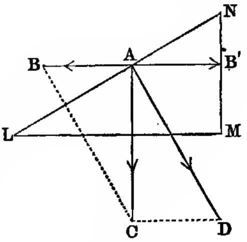


FIG. 57.

204. The Third Case.—For the third case, the power acting in a direction parallel to neither the length nor the base of the plane, no law can be given. The ratio of the power to the weight may be determined by resolving the force of gravity, as above explained, the construction and measurement being carefully done.

EXERCISES.

Remark.—The first problem may be read:

(*a.*) In a system of pulleys, the weight being supported by two sections of the cord, a power of 25 lbs. will support what weight?

(*b.*) In an inclined plane, the power acting in the direction of the length of the plane, the height of the plane being 3 ft., what must be the length that the same power may support the same weight?

No.	POWER.	WEIGHT.	PULLEY.	INCLINED PLANE.			
			Cords.	Height.	Length.	Base.	Case.
1	25 lbs.	?	2	3 ft.	?	......	1
2	13 Kg.	78 Kg.	?	?	12 m.	......	1
3	12 oz.	?	8	?	......	2 ft.	2
4	250 g.	2 Kg.	?	1 dm.	?	......	1
5	?	350 lbs.	7	?	......	49 ft.	2
6	15 cwt.	3 T.	?	4 rds.	?	......	1
7	20 g.	1 Hg.	?	?	......	10 m.	2
8	500 Kg.	?	8	?	24 m.	......	1
9	?	540 lbs.	9	39.37 in.	? m.	......	1
10	75 lbs.	100 lbs.	....	3 yds.	?	?	2

11. With a fixed pulley, what power will support a weight of 50 pounds?

12. With a movable pulley, what power will support a weight of 50 pounds?

13. What is the greatest effect of a system of 3 movable and 4 fixed pulleys, the power applied being 75 pounds?

14. With a system of 5 movable pulleys, one end of the rope being attached to the fixed block, what power will raise a ton?

15. If in the system mentioned in the problem above, the rope be attached to the movable block, what power will raise a ton?

16. With a pulley of 6 sheaves in each block, what is the least power that will support a weight of 1,800 pounds, allowing $\frac{1}{4}$ for friction? What will be the relative velocities of P and W?

17. Figure a set of pulleys by which a power of 50 pounds will support a weight of 250 pounds.

18. The height of an inclined plane is one-fifth its horizontal base. A globe weighing 250 *Kg.* is supported in place by a force acting at an angle of 45° with the base. The pressure of the globe upon the plane is *less* than 250 *Kg.* By construction and measurement, determine the intensity of the supporting force.

19. With the conditions as given in the last problem, except that the pressure of the globe upon the plane is *more* than 250 *Kg.*, determine the intensity of the supporting force.

20. The base of an inclined plane is 10 feet; the height is 3 feet. What force, acting parallel to the base, will balance a weight of 2 tons?

21. An incline has its base 10 feet; its height, 4 feet: how heavy a ball will 50 pounds power *roll up?*

22. How great a power will be required to support a ball weighing 40 pounds on an inclined plane whose length is 8 times its height?

23. A weight of 800 pounds rests upon an inclined plane 8 feet high, being held in equilibrium by a force of 25 pounds acting parallel to the base. Find the *length* of the plane.

24. A load of 2 tons is to be lifted along an incline. The power is 75 pounds; give the ratio of the incline which may be used.

25. A 1500 pound safe is to be raised 5 feet. The greatest power that can be applied is 250 pounds. Give the dimensions of the shortest inclined plane that can be used for that purpose.

Recapitulation.—To be amplified by the pupil for review.

PULLEY.
- DEFINITION.
- KINDS.
  - FIXED.
  - MOVABLE.
  - COMBINATIONS.
- LAW.
- RELATION between the number of pulleys and the number of parts of the cord.

INCLINED PLANE.
- DEFINITION.
- FORCE OF GRAVITY RESOLVED.
  - FIRST CASE.—LAW.
  - SECOND CASE.—LAW.
  - THIRD CASE.

SECTION IV.

THE WEDGE, SCREW, COMPOUND MACHINES, AND FRICTION.

205. What is a Wedge?—*A wedge is a movable inclined plane in which the power generally acts parallel to the base.*

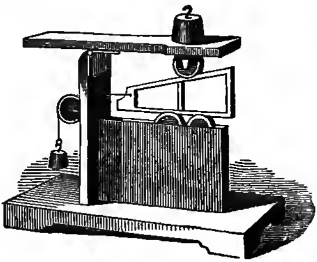


FIG. 58.

206. Its Use.—*The wedge is used for moving great weights short distances.* The law is the same as for the corresponding inclined plane. A common method of moving bodies is to place two similar wedges, with their thin ends overlapping, under the load. Simultaneous blows of equal force are struck upon the heads of the wedges. In this case, the same force must be used upon each wedge as if only one were used, but the power being doubled

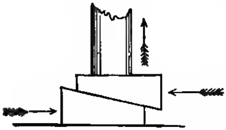


FIG. 59.

and the weight remaining the same, the distance moved is twice as great as when only one wedge is used.

207. A More Common Use.—*A more common kind of wedge is that of two inclined planes united at their bases.* Such wedges are used in splitting timber, stone, etc. The power is given in repeated blows instead of continued pressure. For a wedge thus used, no definite law of any practical value can be given, further than that, with a given thickness, the longer the wedge the greater the gain in intensity of power.


Fig. 60.

208. What is a Screw?—*A Screw is a cylinder, generally of wood or metal, with a spiral groove or ridge winding about its circumference.* The spiral ridge is called the *thread* of the screw. The thread works in a nut, within which there is a corresponding spiral groove to receive the thread.

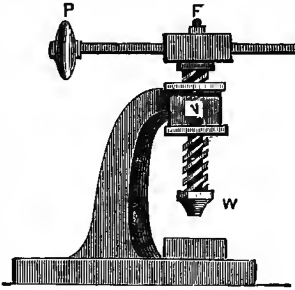


Fig. 61.

(*a.*) The power is used to turn the screw within a fixed nut, or to turn the nut about a fixed screw. In either case, a lever or wheel is generally used to aid the power. Every turn of the screw or nut either pushes forward the screw or draws back the nut by exactly the distance between two turns of the thread, this distance being measured in the direction of the axis of the screw. The weight or resistance at W is moved this distance, while the power at P moves over the circumference of a circle whose radius is PF. The difference between these distances is generally very great. Hence this machine affords great intensity of power with a corresponding loss of velocity.

209. Law of the Screw.—The second general law of machines (§ 167, [2]) may be adapted to our present purpose as follows: *With the screw, a given power will support a weight as many times as great as itself as the circumference described by the power is times as great as the distance between two adjoining turns of the thread.*

210. The Endless Screw.—*An endless screw is one whose thread acts on the teeth of a wheel.* The screw has a rotary but no lengthwise motion. As the handle is turned, the thread catches the teeth and turns the wheel. The wheel moves one tooth for every turn of the handle. Successive teeth are caught as others pass out of reach. A *continuous* motion is thus produced; hence the name "endless screw." The figure will aid in the application of the second general law of machines to determine the ratio between the weight and the power.

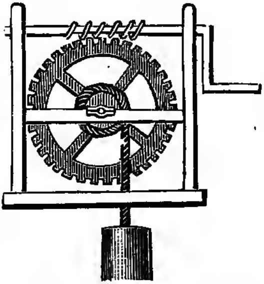


FIG. 62.

211. Compound Machines.—We have now considered each of the six traditional simple machines. One of these may be made to act upon another of the same kind, as in the case of the compound lever or wheel-work; or upon another of a different kind, as in the case of the endless screw. When any two or more of these machines are combined, the effective force may be found by computing the effect of each separately and then compounding them; or by finding the weight that the given power will support, using the first machine alone, considering the result as a new power acting upon the second machine, and so on.

212. What is Friction?—The chief impediment to the motion of machinery arises from friction, which may be defined as *the resistance which a moving body meets with from the surface on which it moves.*

213. The Cause of Friction.—It is impossible, by any known means, to produce a perfectly smooth surface. Even a polished surface contains minute projections which fit into corresponding depressions on the corresponding surface. To produce motion of one surface on the other, these projections must be lifted out, bent down, or broken off.

214. Eight Facts Concerning Friction.—The following facts have been determined by experiment, and may be easily illustrated in the same way:

(1.) *Friction is greatest at the beginning of motion.* After surfaces have been in contact for some time, so that the projections of one have had opportunity to sink deeper into the depressions of the other, the resistance offered by friction is considerably increased. Every teamster and street-car driver is familiar with the fact.

(2.) *Friction increases with the roughness of the surfaces.*

(3.) *Friction is greater between soft bodies than hard ones.*

(4.) *Friction is nearly proportional to pressure.*

(*a.*) Place a brick upon a horizontal board. Around it fasten one end of a cord and pass the other end over a pulley so that it may hang vertically. Add just weights enough to keep the brick in motion after it is started. The weights measure the friction. Place a second similar brick upon the first; the moving force must be doubled. Place another similar brick upon the other two; the original moving force must be tripled.

(5.) *Friction is not affected by extent of surface except within extreme limits.* In the case of the brick above mentioned, the moving force will be the same whether the brick lie on its broad face or on its side.

(6.) *Friction is greater between surfaces of the same material than between those of different kinds.*

(*a.*) Bodies of the same material have the same molecular structure (§ 10, *a*). Hence their little projections and cavities mutually fit each other as would the teeth of similar saws. A very little reflection will show that the element of *similarity* in molecular structure (just as with the saws) is very important in determining the amount of friction. For this reason, the axles of railway cars being made of steel, the "boxes" in which they revolve are made of brass or other different metal. Hence the advantages of a watch "full-jewelled," and hence the swiftness of the skillful skater.

(7.) *Rolling friction is less than sliding friction.*

(8.) *Friction is diminished by polishing or lubricating the surfaces.* An unequalled example of friction reduced to its *minimum* is in the case of the joints of animals.

EXERCISES.—*The Screw.*

No.	P.	W.	C.	*d.*	No.	P.	W.	C.	*d.*
1	15 lbs.	?	10 in.	¼ in.	8	?	2500 Kg.	2.5 m.	1 cm.
2	5 Kg.	?	8 m.	1 cm.	9	4 oz.	6 lbs.	?	7 in.
3	1 lb.	?	75 in.	¼ in.	10	? lbs.	7874 lbs.	1 m.	1 in.
4	?	480 lbs.	15 in.	⅛ in.	11	3 Kg.	300 Kg.	20 cm.	?
5	20 lbs.	800 lbs.	?	½ in.	12	3 oz.	864 oz.	?	1 in.
6	25 lbs.	?	3 ft.	1 in.	13	100 lbs.	?	10 ft.	¾ in.
7	2 lbs.	192 lbs.	4 ft.	?	14	100 lbs.	?	10 ft.	¼ in.

15. A book-binder has a press; the threads of its screw are ⅓ in. apart; the nut is worked by a lever which describes a circumference of 8 ft. How great a pressure will a power of 15 lbs. applied at the end of the lever produce, the loss by friction being equivalent to 240 lbs.?

16. A screw has 11 threads for every inch in length. If the lever is 8 inches long, the power, 50 pounds, and friction is ⅓ of the energy used, what resistance may be overcome by it?

17. A screw with threads 1¼ in. apart is driven by a lever 4½ ft. long; what is the ratio of the power to the weight? (See Appendix A.)

18. How great a pressure will be exerted by a power of 15 lbs. applied to a screw whose head is one inch in circumference and whose threads are ⅛ inch apart?

19. At the top of an inclined plane which rises 1 ft. in 20 is a wheel and axle. Radius of wheel=2½ ft.; radius of axle=4½ in. What load may be lifted by a boy who turns the wheel with a force of 25 lbs.?

20. The crank of an endless screw whose threads are an inch apart describes a circuit of 72 inches. The screw acts on the toothed edge of a wheel 60 inches in circumference. On the axle of this wheel, which is 10 inches in circumference, is wound a cord which acts upon a set of pulleys, 3 in each block. The effect of the pulleys is exerted upon the wheel of a wheel and axle. The diameters of the wheel and of the axle are 4 ft. and 6 inches respectively. What weight on the wheel and axle may be lifted by a force of 25 lbs. at the crank, allowing for a loss of ⅓ by friction?

21. An endless screw which is turned by a wheel 10 ft. in circumference acts upon a wheel having 81 teeth; this wheel has an axle 18 inches in circumference; the power is 75 lbs. Find the value of the weight that may be suspended from the axle.

22. In moving a building the horse is attached to a lever 7 feet long, acting on a capstan barrel 11 inches in diameter; on the barrel winds a rope belonging to a system of 2 fixed and 3 movable pulleys. What force will be exerted by 500 pounds power, allowing ¼ for loss by friction?

Recapitulation.—To be amplified by the pupil for review.

WEDGE. { DEFINITION.
TWO USES AND THE LAW FOR EACH.

SCREW. { DEFINITION.
LAW.
ENDLESS SCREW; ITS ADVANTAGES; RELATION OF P TO W.

COMPOUND MACHINES; RELATION OF P TO W.

FRICTION. { DEFINITION.
CAUSE.
EIGHT FACTS.

REVIEW QUESTIONS AND EXERCISES.

1. (*a.*) What is a machine? (*b.*) What is a machine good for? (*c.*) State the general laws of machines and (*d*) illustrate by the pulley

2. (*a.*) What are the *arms* of a lever? (*b.*) What is meant by the moment of a force? (*c.*) Illustrate the equality of moments in machines by the wheel and axle.

3. (*a.*) What are the respective advantages to be gained by the several classes of levers? (*b.*) Explain the advantage gained by a claw hammer in drawing a nail. (*c.*) What is meant by double weighing?

4. With a lever of given length, in which class will a given power yield the greatest intensity of effect?

5. (*a.*) To what kind of a lever is ordinary clock-work analogous? (*b.*) Show why.

6. (*a.*) Does it require *more work* to lift a barrel of flour into a wagon four feet high than to place it there by rolling it up a plank 12 feet long? (*b.*) Show why.

7. (*a.*) Give the static law for the inclined plane when the power acts parallel to the plane. (*b.*) When it acts parallel to the horizon. (*c.*) Figure a system of pulleys by means of which a weight of 5 pounds will support a weight of 25 pounds.

8. (*a.*) Figure a system of 4 movable pulleys by means of which a weight of 3 lbs. will support a weight of 27 lbs. (*b.*) Deduce the formula for the screw from one of the general laws of machines.

9. (*a.*) In raising a boy from a deep well by means of a common rope and pulley, what disadvantages arise from friction? (*b.*) What immense advantage?

10. (*a.*) Explain the cause of friction. (*b.*) Why is friction between iron and iron greater than that between iron and brass?

11. (*a.*) How may the centre of gravity of a ring be determined? (*b.*) What is the value in inches of the metric unit of length?

12. A body moving with an energy of 20 foot-pounds, strikes the end of the arm of a lever of the first class, four feet from the fulcrum. (*a.*) How many foot-pounds will be exerted by the other end of the lever, 6 feet from the fulcrum? (*b.*) How far would it raise a weight of 4 pounds?

13. Deduce the static law for the inclined plane, first case, by resolution of the force of gravity.

14. (*a.*) What force is necessary to overturn a body? (*b.*) What difference between the forces producing uniform and accelerated velocities? (*c.*) Show that the screw is a modified inclined plane.

CHAPTER IV.

LIQUIDS.

SECTION I.

HYDROSTATICS.

215. Incompressibility of Liquids.—Liquids are nearly incompressible. A pressure of 15 pounds to the square inch compresses distilled water only $\frac{1}{200000}$ part of its volume; it compresses mercury only one-tenth as much. This virtual incompressibility of liquids is of the highest practical importance.

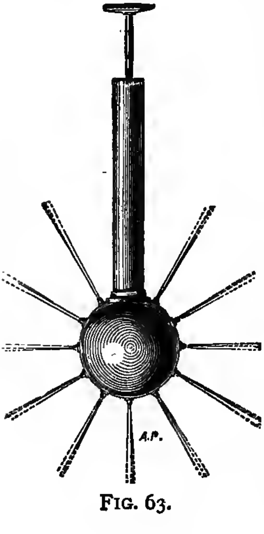


FIG. 63.

216. Transmission of Pressure.—*Fluids can transmit pressure in every direction, upward, downward, and sidewise at the same time.*

(*a.*) This property of liquids may be illustrated by the apparatus represented in Fig. 63. The globe and cylinder being filled with water and the several openings in the globe closed by corks, a piston is pushed down the cylinder. The pressure thus received and transmitted by the confined water expels the cork and throws a jet of water from each aperture. (See Appendix D.)

(*b.*) The explanation of this property of fluids may be seen by reference to Fig. 64, representing five molecules of any fluid. If a downward pressure be applied to 1, it will force 2 toward the right and 3 toward the left, thus forming lateral pressure. When thus moved, 3 will force 4 upward and 5 downward. Owing to the freedom with which the molecules move on each other, there is no loss by friction, and the downward pressure of 5, the upward pressure of 4, and the lateral pressure of 2, will each equal the pressure exerted by 1. It makes no difference with the fact, whether the pressure exerted by 1 was the result of its own weight only, this weight together with the weight of overlying molecules, or both of these with still additional forces.

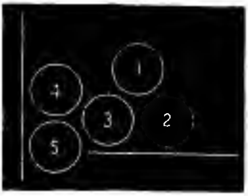


FIG. 64.

217. Pascal's Law.—*Pressure exerted anywhere upon a mass of liquid is transmitted undiminished in all directions, and acts with the same force upon all equal surfaces and in a direction at right angles to those surfaces.*

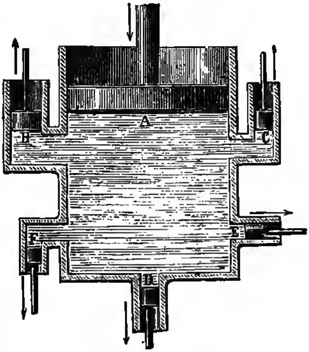


FIG. 65.

218. An Argument from Pascal's Law.—Fill with water a vessel of any shape, having in its sides apertures whose areas are respectively as 1, 2 and 3, each aperture being closed with a piston. Suppose the pistons to move without friction and the water to have no weight; then there will be no motion. Suppose that the piston whose area is represented by 1 rests upon 1000 molecules of the water; then will the piston at 2 rest upon 2000, and that at 3 upon 3000 molecules of water. If now a pressure of one pound be applied to the piston at 1, this pressure is distributed among the 1000 molecules upon which it presses. Owing to this freedom of motion, these molecules will transmit this pressure to those adjacent, and these to those beyond, until every molecule of water in the vessel exerts a pressure equal to that exerted upon any one of the molecules upon which the pressure was originally exerted, *i. e.*, every thousand molecules in the vessel will exert a force of one pound. Then will the 2000 molecules at 2 exert a force of two pounds and the 3000 molecules at 3 will exert a force of three pounds.

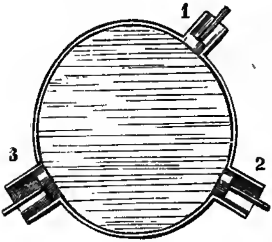


FIG. 66.

219. An Important Principle.—The foregoing argument may be summed up as follows: *When fluids are subjected to pressure, the pressure sustained by any part of the restraining surface is proportional to its area.*

220. Experimental Proof.—The above principle, which we deduced from Pascal's law, may be verified by experiment. Provide two communicating tubes of unequal sectional area. When water is poured into these, it will stand at the same height in both tubes. If by means of a piston the water in the smaller tube be subjected to pressure, the pressure will force the water back into the larger tube and raise its level there. To prevent this result, a piston must be fitted to the larger tube and held there with a force as many times greater than the force acting upon the other

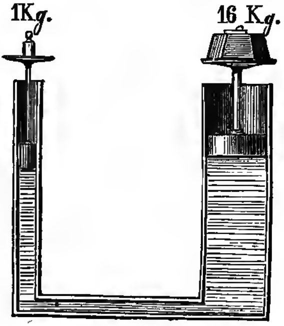


FIG. 67.

piston as the area of the larger piston is times greater than the area of the smaller one. If, for example, the smaller piston have an area of 1 sq. cm. and the larger piston an area of 16 sq. cm., a weight of 1 Kg. may be made to support a weight of 16 Kg.

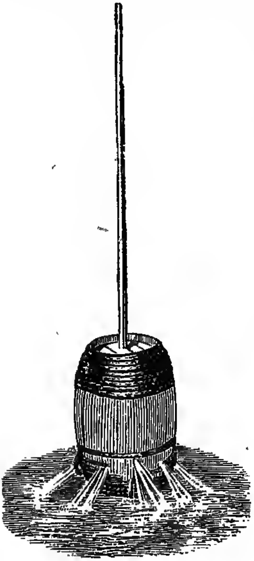


FIG. 68.

221. Pascal's Experiment—Pascal firmly fixed a very narrow tube about 30 ft. high into the head of a stout cask. He then filled the cask and tube with water. The weight of the small amount of water in the tube, producing a pressure as many times greater than itself as the inner surface of the cask was times greater than the sectional area of the tube, actually burst the cask.

222. The Hydrostatic Bellows.—*The hydrostatic bellows consists of two boards fastened together by a broad band of stout leather, and a small vertical tube communicating with the interior.* If the tube have a sectional area of 1 sq. cm., the downward pressure at *b*, its base, will be one gram for every centimeter of depth of water in the tube. If the upper board, *B*, have a surface of 1000 sq. cm. exposed to the water in the bellows, it will be pressed upward with a

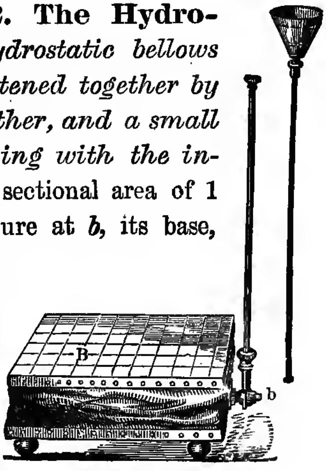


FIG. 69.

force of 1000 g. for every gram of downward pressure at *b*. If the tube be 2 meters high the downward pressure at *E* will be 200 g., and the upward pressure exerted on *B* will be 200 g. × 1000 = 200,000 g. or 200 Kg.

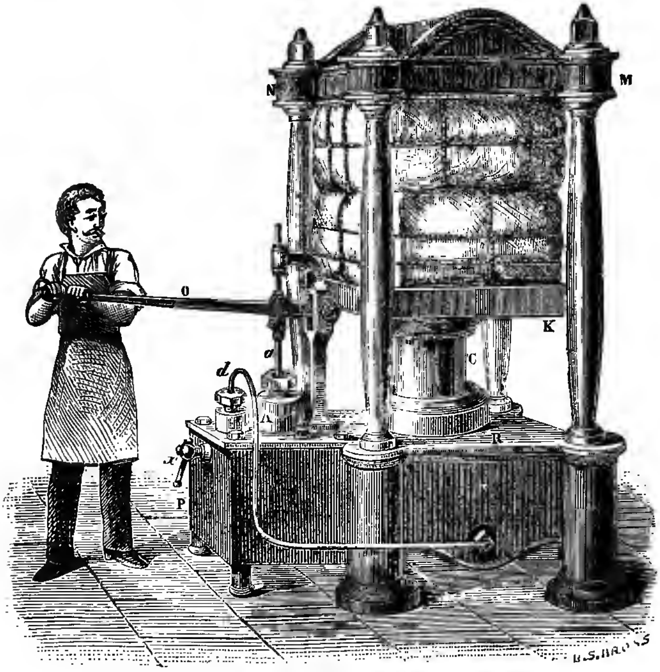


FIG. 70.

223. The Hydrostatic Press.—The hydrostatic press, often called the Hydraulic, or Bramah's press, acts upon the same principle. It is represented in perspective by Fig. 70 and in section by Fig 71. Instead of the downward pressure produced by the weight of the water in the tube, pressure is produced by the force-pump. Instead of the two boards and the leather band, a large,

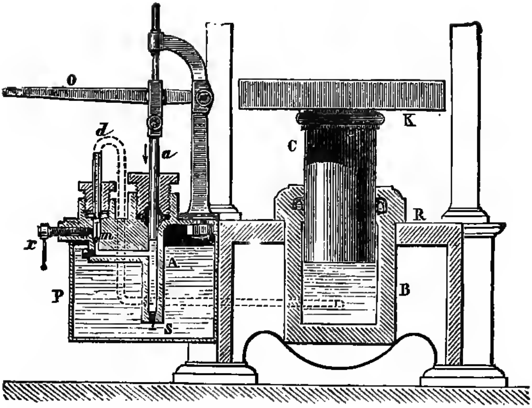


FIG. 71.

strong reservoir and a piston, working water-tight, are used. The substance to be pressed is placed between K, the head of the piston, and an immovable plate MN. The reservoir and the cylinder of the pump are connected by the tube *d*. By the action of the pump, the water in the cylinder *A* is subjected to pressure, and this pressure is transmitted undiminished to the water in *B*. According to the law given in § 219, the power exerted upon the lower surfaces of the two pistons is proportional to their respective areas. But the force exerted by the water upon the under surface of the piston in the pump is the same as the force exerted upon the water by that piston, (equality of action and reaction). The piston *a* is generally worked by a lever of the second class, resulting in a still further gain of intensity of power. If the power arm of the lever be ten times as long as the weight-arm, a power of 50 Kg. at the end of the lever will exert a pressure of 500 Kg. upon the water in *A*. If the piston in *A* have a sectional area of 1 sq. cm. and the piston in *B* have an area of 500 sq. cm., then the pressure of 500 Kg. exerted by the small piston will produce a pressure of 500 Kg. × 500 = 250,000 Kg. upon the lower surface of the large piston. Hence the following rule:

Multiply the pressure exerted by the piston of the pump by the ratio between the sectional areas of the two pistons.

(*a.*) The accompanying figure shows a device due to Ritchie of Boston. It consists of a base B; a sliding platform P guided by two vertical pillars; a bellows-formed rubber bag connecting the base and platform; and a bag or flask F, fitted with a cap and cork. The flask is connected with the base by flexible tubing. A weight W is placed upon the platform. Fill the globe with water, and elevate it; the pressure of the column will force the water into the bellows, raising the weight; lower the globe, and the weight will force the water back into it.

FIG. 72.

224. Liquid Pressure Due to Gravity.

224. Liquid Pressure Due to Gravity.—The pressure exerted by liquids, on account of their weight, may be downward, upward, or lateral. Pressure in any other direction may be resolved into two of these. We shall now briefly consider these three kinds of liquid pressure.

225. Downward Pressure.—*The pressure on the bottom of a vessel containing a liquid, is independent of the quantity of the liquid or the shape of the vessel, but depends upon the depth and density of the fluid and the area of the bottom.*

(*a.*) Pascal contrived a neat experiment to verify this principle. The apparatus consists of a wooden support carrying a ring into which may be screwed any one of three vessels, one cylindrical, one widening upward and one narrowing upward, straight or bent. On the lower side of the ring is a plate *a*, supported by a thread from one end of an ordinary balance. The other end of the balance carries a scale-pan. Weights in the scale-pan hold the plate *a* against the ring with a certain force. Water is carefully poured into M until the pressure forces off the plate and allows a little of the water to escape. A rod *o* marks the level of the liquid when this takes place. Repeating the experiment with the same weights in the scale-pan, and either P or Q in the place of M. the plate will be detached when the water has reached the same height although the quantity of water is much less.

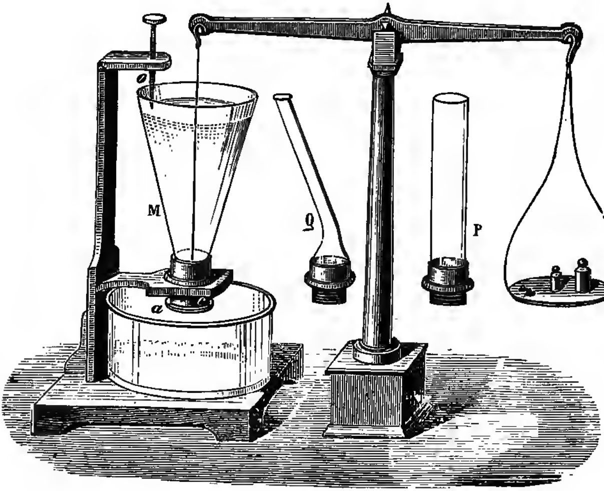


FIG. 73.

226. Rule for Downward Pressure.

—When the cylindrical vessel, mentioned in the last paragraph, is filled, it is evident that the downward pressure is equal to the weight of the contained liquid. It is further evident that the weight of the counterpoise in the scale-pan, the weight of the liquid contained in P, and the downward pressure exerted on the plate by the liquid contained in M, P, or Q are equal. We therefore deduce the following rule:

To find the downward pressure on a horizontal surface, find the weight of an imaginary column of the given liquid, whose base is the same as the given surface, and whose altitude is the same as the depth of the given surface below the surface of the liquid.

Note.—A cubic foot of water weighs about 1000 ounces, 62½ pounds (more exactly 62.42 lbs.).

227. Upward Pressure.—Some persons have difficulty in understanding that liquids have *upward* pressure. This upward pressure may be illustrated as follows: Take a glass tube open at both ends, having at its lower end a glass or mica disc supported from its centre by a thread. If this apparatus be placed in water, the tube being vertical, the upward pressure of the water will hold the disc in its place. If the disc does not accurately fit the end of the tube, water will be forced into the tube, and gradually fill it from below. If the disc does fit accurately, as is desirable, pour water carefully into the tube. In either case, the disc will be

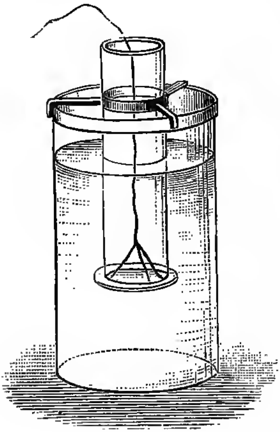


FIG. 74.

held in place against the force of gravity until the level of the water within the tube is very nearly the same as that in the outer vessel. The disc will not fall until the weight of the water in the tube *plus* the weight of the disc equals the upward pressure.

Note.—A lamp-chimney answers the purpose of this experiment. On the glass disc pour a little fine emery powder, and on this rub the end of the lamp-chimney until they fit accurately. The string may be fastened to the disc with wax.

228. Rule for Upward Pressure.—*To find the upward pressure on any horizontal surface, find the weight of an imaginary column of the given liquid whose base is the same as the given surface, and whose altitude is the same as the depth of the given surface below the surface of the liquid.*

229. The Hydrostatic Paradox.—It may seem strange at first thought that vessels whose bottoms are subjected to equal pressure, like those represented in Fig. 75, do not exert equal pressures upon the stand supporting them; in other words, that they do not weigh the same. The difficulty will be removed by remembering that *the pressure on the bottom of the vessel is only one of the elements which combine to produce the pressure upon the stand.* By reference to the figure, which represents three vessels of unequal capacity but having equal pressures upon the bot-

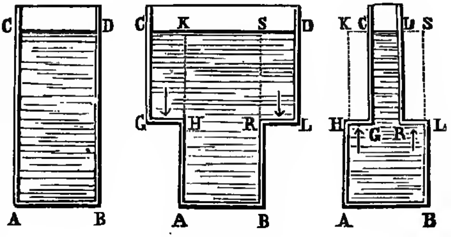


FIG. 75.

tom, it will be seen that the weight may be the resultant of several forces, compounded according to the first and second cases specified in § 80.

230. Lateral Pressure.—We have already seen that downward and upward pressure are proportional to the depth of the liquid. Owing to the principle of equal transmission of pressure in all directions, the same holds true for lateral pressure, the effects of which are sometimes disastrously shown by the giving way of flood-gates, dams, and reservoirs.

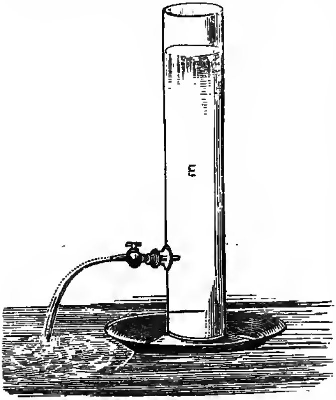


Fig. 76.

(*a.*) These effects of lateral pressure may be safely illustrated by a tall vessel provided with a stop-cock near its base, and arranged to float upon the water. When this vessel is filled with water, the lateral pressure at any two points at the same depth and opposite each other will be equal. Being equal and opposite they will neutralize each other and produce no motion. If now the stop-cock be opened, the pressure at that point tending to drive the apparatus in a certain direction, say toward the left, is removed; the pressure at the opposite point tending to drive the vessel toward the right, being no longer opposed by its equal, will now produce motion and the vessel will float in a direction opposite to that of the spouting water. Instead of being floated upon water, the vessel may be supported by a long thread. The same principle is illustrated in Barker's Mill. (Fig. 91.)

231. Rule for Lateral Pressure.—*To find the pressure upon any vertical surface, find the weight of an imaginary column of the liquid whose base is equal to the given surface and whose altitude is the same as the depth of the centre of the given surface below the surface of the liquid.*

EXERCISES.

1. What will be the pressure on a dam in 20 feet of water, the dam being 30 feet long?

2. What will be the pressure on a dam in 6 *m.* of water, the dam being 10 *m.* long?

3. Find the pressure on one side of a cistern 5 feet square and 12 feet high, filled with water.

4. Find the pressure on one side of a cistern 2 *m.* square and 4 *m.* high, filled with water.

5. A cylindrical vessel having a base of a sq. yd., is filled with water to the depth of two yards. What pressure is exerted upon the base?

6. A cylindrical vessel having a base of a *sq. m.* is filled with water to the depth of two meters. What pressure is exerted upon the base?

7. What will be the upward pressure upon a horizontal plate a foot square at a depth of 25 ft. of water?

8. What will be the upward pressure upon a horizontal plate 30 *cm.* square at the depth of 8 *m.* of water?

9. A square board with a surface of 9 square feet is pressed against the bottom of the vertical wall of a cistern in which the water is 8½ feet deep. What pressure does the water exert upon the board?

10. A cubical vessel with a capacity of 1728 cubic inches is two-thirds full of sulphuric acid, which is 1.8 times as heavy as water. Find the pressure on one side.

11. A conical vessel has a base with an area of 237 *sq. cm.* Its altitude is 38 *cm.* It is filled with water to the height of 35 *cm.* Find the pressure on the bottom. *Ans.* 8295 *g.*

12. In the above problem, substitute inches for centimeters, and then find the pressure on the bottom.

13. What would be the total liquid pressure on a prismatic vessel containing a cubic yard of water, the bottom of the vessel being 2 by 3 feet?

14. The lever of a hydrostatic press is 6 feet long, the piston-rod being 1 foot from the fulcrum. The area of the tube is one-half square inch; that of the cylinder is 100 square inches. Find the weight that may be raised by a power of 75 lbs

15. What is the pressure on the bottom of a pyramidal vessel filled with water, the base being 2 by 3 feet, and the height, 5 feet?

16. What is the pressure on the bottom of a conical vessel 4 feet high filled with water, the base being 20 inches in diameter?

Recapitulation.—In this section we have considered Incompressibility; the Transmission of Pressure with Explanation and Illustration; Pascal's Law with Argument and Conclusion therefrom; one of Pascal's Experiments; the Hydrostatic Bellows; the Hydrostatic Press; Downward Pressure with experimental illustrations; Rule for computing downward pressure; Upward Pressure with experimental illustrations; Rule for computing upward pressure; Lateral Pressure with experimental illustrations; Rule for computing lateral pressure.

SECTION II.

EQUILIBRIUM.—CAPILLARITY.—BOUYANCY.

232. Conditions of Liquid Rest.—The force of gravity tends to draw all liquid particles as near the earth's centre as possible. The following are necessary conditions, that a liquid may be at rest:

(1.) *The free surface of the liquid must be everywhere perpendicular to the force of gravity, i. e.,* horizontal. In the case of the ocean, this condition is modified by the so-called centrifugal force, which gives rise to the spheroidal shape of the earth.

(2.) *Every molecule must be subjected to equal and contrary pressures in every direction.*

233. Equilibrium of Liquids.—A liquid of small surface area is said to be level when all the points of its surface are in the same horizontal plane. The central idea is expressed in the familiar saying, *water seeks its level.* This is true whether the liquid be placed in a single vessel or in several vessels that communicate with each other.

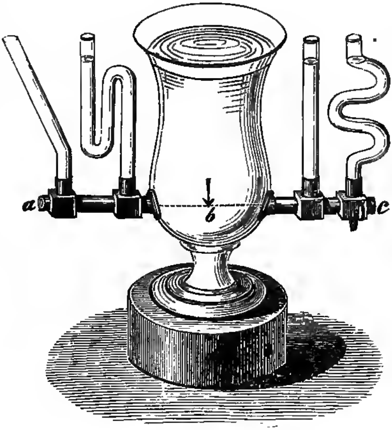


FIG. 77.

234. Communicating Vessels.—When any liquid is placed in one or more of several vessels communicating with each other, *it will not come to rest until it stands at the same height in all of the vessels,* so that all of the free surfaces lie in the same horizontal plane. This principle is prettily illustrated by the apparatus represented in Fig. 77. It consists of such communicating vessels containing a liquid.

(*a.*) This important principle that "water seeks its level" finds a gigantic illustration in the system of water-pipes by which water is distributed in cities and large towns. Brought or pumped into an elevated reservoir near the city, the water flows, in obedience to the force of gravity, through all the turns and windings of all the pipes connected with the reservoir, and is thus brought into thousands of buildings. Into any of these rooms of any of these houses the water may thus be led, *provided only* that the ends of the pipes be below the level of the water in the reservoir.

(*b.*) Among the many other results of this tendency of water to seek its level may be mentioned the action of springs and Artesian wells, the use of locks on canals, the spirit-level, the flow of streams, etc.

235. Capillary Attraction. — The statements made concerning the equilibrium of liquids are subject to one important modification. When the vertical sides of the containing vessel are very near each other, as in the case of small tubes, we have a manifestation of what is called *capillary attraction.*

236. Capillary Phenomena.—If a clean glass rod be placed vertically in water, the water will rise above its level at the sides of the glass. If the rod be now plunged into mercury, this liquid will be depressed instead of raised. If the experiments be repeated, it may be noticed that the water *wets the glass* while the mercury does not. If the glass be smeared with grease and placed in water, the surface of the water will be depressed; if a clean lead or zinc plate be placed in the mercury the surface of the mercury will be raised. In this case the greased glass will come out dry, no water adhering to it, while mercury will adhere to the lead or zinc. This is found to be invariably true: *all liquids that will wet the sides of solids placed in them will be lifted, while those that do not will be pushed down.* In the figure, *a* represents

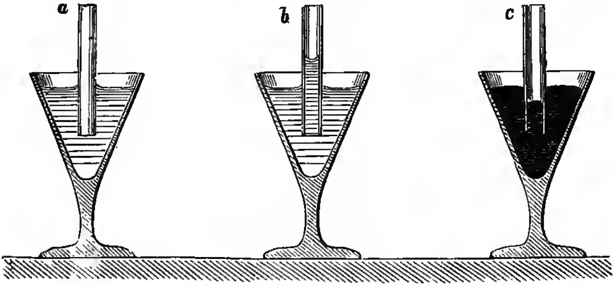


FIG. 78.

a glass rod in water; *b*, a glass tube in water; and *c*, a glass tube in mercury.

(*a*.) This so-called attraction is said to be "capillary" because its phenomena are best shown in tubes as fine as a hair (Latin, *capillus*). If fine glass tubes be placed in water, the liquid will rise, wet the tube, and have a concave surface. If they be placed in mercury, the liquid will be depressed, will not wet the tube, and will have a convex surface. *The finer the tube, the greater the capillary ascent or depression.*

237. Displacement of a Fluid by an Immersed Solid.—*A solid immersed in a fluid will displace exactly its own bulk of the fluid.* This may be proved, if desirable, by plunging a heavy body of known volume, as a cubic centimeter of iron, into water contained in a glass vessel graduated to cubic centimeters. The water will rise just as if another cubic centimeter of water had been added. Thus, the volume of any irregularly shaped body may be found.

238. Archimedes' Principle.—*The loss of weight of a body immersed in a fluid equals the weight of the fluid which it displaces.*

(*a*.) It is a familiar fact that a person may easily raise to the surface of the water a stone which he cannot lift any further. When an arm or leg is lifted out of the water of a bath-tub, there is a sudden and very perceptible increase of weight at the surface Let us try to find a reason for these familiar truths. Imagine a cube, six centimeters on a side, immersed in water so that four of its surfaces are vertical and its upper horizontal surface twelve centimeters below the surface of the water. The lateral pressures which the water exerts upon any two opposite vertical surfaces are clearly equal and opposite. They will have no tendency to move the body. But the vertical pressures upon the two horizontal surfaces are not equal. The lower face will be pressed upward with a force represented by the weight of (6 × 6 × 18 =)

FIG. 79.

648 *cu. cm.* of water (see § 228) while the upper face will be pressed downward with a force represented by the weight of (6 × 6 × 12 =) 432 *cu. cm.* of water. The resultant of all these forces, therefore, will be a net upward pressure represented by the weight of (648—432=) 216 *cu. cm.* of water. But 216 *cu. cm.* is the volume of the cube. *This net upward pressure or buoyant effort is exerted against the force of gravity,* and diminishes the weight of the cube.

239. An Experimental Demonstration.— This principle of Archimedes may be experimentally verified as follows: From one end of a scale-beam suspend a cylindrical bucket of metal, *b*, and below that a solid cylinder, *a*, which accurately fits into the bucket. Counterpoise with weights in the opposite scale-pan. Immerse *a* in water and the counterpoise will descend, showing that *a* has lost some of its weight. Carefully fill *b* with water. It will hold exactly the quantity displaced by *a*. Equilibrium will be restored.

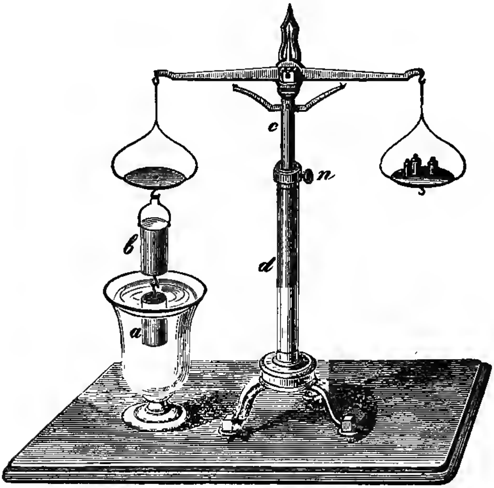


FIG. 80.

(*a*.) Insert a short spout in the side of a vessel (as a tin fruit-can) about an inch below the top. Fill the vessel with water and let all above the level of the spout escape. This is to replace the vessel of water in which *a* (Fig. 80) is immersed. Instead of the bucket, *b*, use a cup placed on the scale pan. Instead of *a*, use any convenient solid heavier than water, as the fragment of a stone. Counterpoise the cup and stone in the air. Immerse the stone in the water and catch, in any convenient vessel, every drop of water that overflows. This will be the fluid that the solid displaces. The equilibrium is destroyed, but may be restored by pouring the water just caught into the cup on the scale-pan.

240. Floating Bodies.—When solids of different densities are thrown into a given liquid, those having densities greater than that of the liquid will sink, because the force of gravity overcomes the buoyancy of the liquid; those having densities equal to that of the liquid will remain at rest in any position in the liquid, because the opposing forces, gravity and buoyancy, are equal; those having densities less than that of the liquid will float, because the force of gravity will draw them down into the liquid until they displace enough of the liquid to render the buoyant effect equal to the weight. Hence, *a floating body displaces its own weight of the fluid.* This may be shown experimentally by filling a vase with water. When a floating body is placed on the surface, the water displaced will overflow and may be caught. The water thus caught will weigh the same as the floating body.

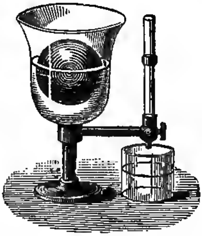


FIG. 81.

(*a*.) Place the tin vessel with a spout, mentioned in the last article, upon one scale-pan, and fill it with water, some of which will overflow through the spout. When the spout has ceased dripping, counterpoise the vessel of water with weights in the other scale-pan. Place a floating body on the water. This will destroy the equilibrium, but water will overflow through the spout until the equilibrium is restored. This shows that the floating body has displaced its own weight of water.

EXERCISES.

1. How much weight will a *cu. dm.* of iron lose when placed in water?

2. How much weight would it lose in a liquid 13.6 times as heavy as water?

3. If the *cu. dm.* of iron weighs only 7780 *g.*, what does your answer to the 2d problem signify?

4. How much weight would a cubic foot of stone lose in water?

5. If 100 *cu. cm.* of lead weigh 1135 *g.*, what will it weigh in water?

6. If a brass ball weigh 83.8 *g.* in air and 73.8 *g.* in water, what is its volume?

7. If a brass ball weigh 83.8 oz. in air and 73.8 oz. in water, what is its volume?

Recapitulation.—In this section we have considered the Conditions of Liquids at Rest; the Equilibrium of liquids in Single and Communicating Vessels; the Water Supply of cities; the Equilibrium of Different Liquids in communicating vessels; Capillary Attraction and some of its Phenomena; Capillary Tubes; the quantity of a Fluid Displaced by an immersed solid; the Buoyancy of Fluids; Archimedes' Principle; several Explanations of Archimedes' Principle and its Experimental Verification; Floating Bodies.

SECTION III.

SPECIFIC GRAVITY.

241. What is Specific Gravity?—*The specific gravity of a body is the ratio between its weight and the weight of a like volume of some other substance taken as a standard.*

242. Standard of Specific Gravity.—The standard taken must be invariable. For solids and liquids, *the standard adopted is distilled water at a temperature of 4° C., or 39.2° F.* For aëriform bodies, the standard is air or hydrogen.

(*a.*) The water is to be distilled, or freed from all foreign substances, because the weight of a given quantity of water varies with the substances held in solution. It is to be at a fixed temperature because of the expansion by heat. The temperature above mentioned is that of water at its greatest density. In cases where air or hydrogen is taken as a standard, the additional condition of atmospheric pressure must, for obvious reasons, be recognized. The pressure to which all observations in this country are reduced is that recorded by 30 inches (760 *mm.*) of the barometer.

243. Elements of the Problem.—*For solids or liquids, the dividend is the weight of the given body; the divisor is the weight of the same bulk of water;* the quotient, which is an abstract number, is the specific gravity, and signifies that the given body is so many times heavier than the standard. The weight of the same bulk of water is found sometimes in one way and sometimes in another, but in *every case it is the divisor.* By grasping and keeping this idea, you will avoid much possible confusion. Of course, when any two of these three are given, the third can be found.

244. To Find the Specific Gravity of Solids.—The most common method of finding the specific gravity of a solid heavier than water, is to find the weight of the body in the air (= W), then suspend the body by a light thread and find its weight in water (= W′), and divide the weight of the body in air by the weight of the same bulk of water (§ 238, Archimedes' Principle).

$$Sp.\,Gr. = \frac{W}{W - W'}.$$

(a.) The method is illustrated by the following example:

Weight of substance in air = 58½ oz.
Weight of substance in water = 51 oz.
Weight of equal bulk of water = 7½ oz.
Specific gravity = 58½ oz. ÷ 7½ oz. = 7.8, *Ans.*

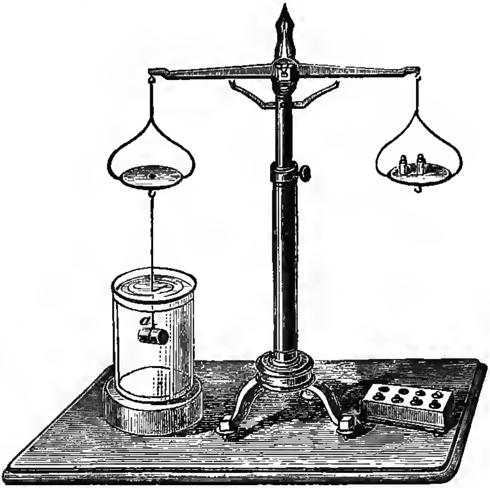


FIG. 82.

245. To Find the Specific Gravity of Solids Lighter than Water.—If the given body be lighter than water, fasten to it some body heavy enough to sink it. Find the loss in weight of the combined mass when weighed in water. Do the same for the heavy body. Subtract the loss of the heavy body from the loss of the combined body. Divide the weight of the given body by this difference. (Show that this divisor is as indicated in § 243.) A modification of this method is to balance the sinker in water. Then attach to it the light substance in question, *e. g.*, a cork, and determine the buoyant effort of the cork, *i. e.*, the weight of its bulk of water. Divide as before.

(*a.*) The first method is illustrated by the following example:

(1.) Weight of cork and iron in air . . . . 82.4 g.
(2.) " " " " " water . . . . 52.4 g.
(3.) " " water displaced by cork and iron . . . . 30. g.
(4.) " " iron in air . . . . 77.8 g.
(5.) " " " water . . . . 67.8 g.
(6.) " " water displaced by iron . . . . 10. g.
(7.) " " " " cork (3) – (6) . . . . 20. g
(8.) " " cork in air . . . . (1) – (4) . . . 4.6 g
(9.) Specific gravity of the cork . . . . (8) ÷ (7) 23
(10.) " " " iron . . . . (4) ÷ (6) 7.78

246. To Find the Specific Gravity of Liquids.—The principle is unchanged. A simple method is as follows: Weigh a flask first empty; next, full of water; then, full of the given liquid. Subtract the weight of the empty flask from the other two weights; the results represent the weights of equal volumes of the given substance and of the standard. Divide as before. A flask of known weight, graduated to measure 100 or 1000 grams or grains of water is called a *specific gravity flask.* Its use avoids the first and second weighings above mentioned, and simplifies the work of division.

247. Another Simple Method.—The specific gravity of a liquid may be easily determined as follows: Find the loss of weight of any insoluble solid in water and in the given liquid.

From § 238, determine what these two losses represent. Divide as before. The solid used is called a *specific gravity bulb.*

Other methods are sometimes used, but as they depend upon the principles already explained, they need not be set forth here. Some of them will be illustrated in the problems.

248. To Find the Specific Gravity of Gases.—The specific gravity of an aëriform body is always found by comparing the weight of equal volumes of the standard (air or hydrogen) and of the given substance. The method is strictly analogous to the one first given for liquids. The air is removed from the flask with an air-pump—an instrument to be studied soon. The accurate determination of the specific gravity of gases presents many practical difficulties which cannot be considered in this place.

Note.—The weight of *any* solid or liquid (in grams per *cu. cm.*) represents its specific gravity. Bodies are commonly weighed in the air. But, in common with all other fluid bodies, *the air has weight and therefore* (§ 238) *diminishes the true weight* of all bodies thus weighed. This diminution is generally disregarded, but in certain delicate operations it must be carefully considered.

249. Hydrometers.—Instruments, called hydrometers or areometers, are made for the more convenient determination of specific gravity. They dispense with the use of the balance, an instrument requiring careful handling and preservation. Hydrometers are of two kinds:

(1.) *Hydrometers of constant volume,* as Nicholson's.

(2.) *Hydrometers of constant weight,* as Beaume's.

250. Nicholson's Hydrometer.—Nicholson's hydrometer is a hollow cylinder carrying at its lower end a basket *d*, heavy enough to keep the apparatus upright when floated on water. At the top of the cylinder is a vertical rod carrying a pan *a*, for holding weights, etc. The whole apparatus must be lighter than water, so that a certain weight ($= W$,) must be put into the pan to sink

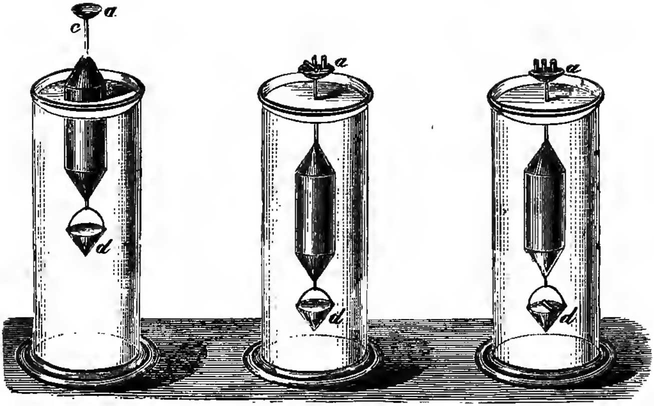


FIG. 83.

the apparatus to a fixed point marked on the rod (as c). The given body, which must weigh less than W, is placed in the pan, and enough weights ($= w$) added to sink the point c to the water line. It is evident that the weight of the given body is $W - w$. It is now taken from the pan and placed in the basket, when additional weights ($= x$) must be added to sink the point c to the water line.

$$Sp.\ Gr. = \frac{W - w}{x}. \quad \text{(Why ?)}$$

251. Fahrenheit's Hydrometer.—Fahrenheit's Hydrometer is similar in form to Nicholson's, but is made of glass instead of metal, so that it may be used in any liquid. The basket is replaced by a bulb loaded with shot or mercury. The weight of the instrument ($= W$) is accurately determined. The instrument is placed in water.

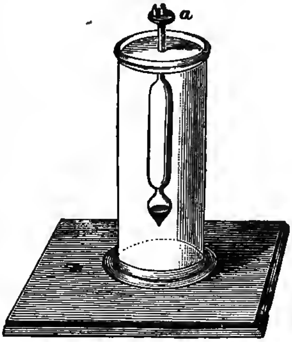


FIG. 84.

and a weight ($= w$), sufficient to sink the point c to the water line, is placed in the pan. The weight of water displaced by the instrument $= W + w$. The hydrometer is now removed, wiped dry, and placed in the given liquid. A weight ($= x$), sufficient to sink the hydrometer to c, is placed in the pan.

$$Sp.\ Gr. = \frac{W + x}{W + w}. \quad \text{(Why ?)}$$

Note.—A Nicholson's hydrometer may be used as a Fahrenheit's in any liquid which has no chemical action upon the metal of which it is made. Neither of these hydrometers gives results as accurate as those obtained by the methods previously given.

252. Constant Weight Hydrometers.—A hydrometer of constant weight consists of a glass tube near the bottom of which are two bulbs. The lower and smaller bulb is loaded with mercury or shot. The tube and upper bulb containing air, the instrument is lighter than water. The point to which it sinks when placed in pure water is generally marked zero. The tube is graduated above and below zero, the graduation being sometimes upon a piece of paper placed within the tube. As a long stem would be inconvenient, it is customary to have two instruments, one having zero near the top, for liquids heavier than water; the other having zero near the bulb, for liquids lighter than water. The scale of graduation is arbitrary, varying with the purpose for which the instrument is intended. These instruments are more frequently used to determine the degree of concentration or dilution of certain

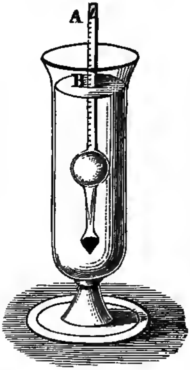


FIG. 85.

liquids, as acids, alcohols, milk, solutions of sugar, etc., than their specific gravities proper. According to their uses they are known as acidometers, alcoholometers, lactometers, saccharometers, etc. They all depend upon the principle that a floating body will displace its own weight of the liquid upon which it floats, and, consequently, a greater *volume* of light than of heavy liquids.

253. Tables of Reference.—(1.) Specific gravities of some solids:

Iridium	23.00	Brass	8.38	Marble (statuary)	2.83
Platinum	22.069	Iron (bar)	7.78	Anthracite Coal	1.80
Gold (forged)	19.36	Tin (cast)	7.29	Bituminous Coal	1.25
Lead (cast)	11.35	Iron (cast)	7.21	Ice (melting)	.92
Silver (cast)	10.47	Zinc (cast)	6.86	Pine	.65
Copper (cast)	8.79	Flint Glass	3.33	Cork	.24

(2.) Specific gravities of some liquids:

Mercury	13.6	Nitric Acid	1.22	Turpentine	.87
Sulphuric Acid	1.84	Milk	1.03	Alcohol	.8
Hydrochloric Acid	1.24	Sea Water	1.026	Ether	.72

(3.) Specific gravities of some gases: (Barometer = 760 *mm.*; Temperature = 32° F. or 0° C.)

AIR = STANDARD.		HYDROGEN = STANDARD.	
Hydroiodic Acid	4.41	Hydroiodic Acid	64
Carbon Dioxide	1.52	Carbon Dioxide	22
Oxygen	1.1	Oxygen	16
Air	1.0	Air	14.5
Nitrogen	.97	Nitrogen	14
Hydrogen	.069	Hydrogen	1

Note.—The weight of a cubic foot of any solid or liquid is equal to 62.421 lbs. avoirdupois multiplied by its specific gravity.

The weight of a cubic centimeter of any solid or liquid is equal to 1 gram multiplied by its specific gravity.

The weight of a liter (or *cu. dm.*) of any solid or liquid is equal to 1 *Kg.* multiplied by its specific gravity.

The tables above give only *average* densities. Any given specimen may vary from the figures there given.

EXERCISES.

Note.—Be on the alert to recognize Archimedes' Principle in disguise. Consider the weight of water 62½ lbs. per cubic foot.

The numbers obtained for the right hand column may be either *plus* or *minus;* the former sign denotes weight in the fluid; the latter, the load it could support in the fluid.

No.	Weight in Air.	Weight in Water.	Loss of Weight in Water.	Spec. Grav.	Volume.	ANY FLUID.	
						Sp. Gr. of	Weight in
1	1500 lbs.	1000 lbs.	?	?	? cu ft.	1.5	?
2	5000 oz.	?	1500 oz.	?	?	?	2000 oz.
3	?	1875 g.	?	2	?	1.8	?
4	?	9375 g.	?	?	?	1.5	4687.5 g.
5	?	?	?	7.5	300 cu. cm.	2.5	?
6	?	1125 lbs.	?	?	?	3	875 lbs.
7	?	?	?	?	8 cu. ft.	13.6	2700 lbs.
8	?	?	?	6.86	5 cu. dm.	13.6	?
9	1 Kg.	?	?	1	?	?	200 g.
10	?	?	?	2.83	10 cu. ft.	.8	?

11. A bone weighs 2.6 ounces in water and 6.6 ounces in air; what is its specific gravity?

12. A body weighing 453 g. weighs in water 429.6 g.; what is its specific gravity?

13. A piece of metal weighing 52.35 g. is placed in a cup filled with water. The overflowing water weighed 5 g. What was the specific gravity of the metal?

14. (*a.*) A solid weighing 695 g. loses in water 83 g.; what is its specific gravity; (*b*) how much would it weigh in alcohol of specific gravity 0.792?

15. A 1000 grain bottle will hold 708 grains of benzoline. Find the specific gravity of the benzoline.

16. A solid which weighs 2.4554 oz. in air, weighs only 2.0778 oz. in water. Find its specific gravity.

17. A specimen of gold which weighs 4.6764 g. in air loses 0.2447 g. weight when weighed in water. Find its specific gravity.

18. A ball weighing 970 grs., weighs in water 895 grs., in alcohol 910 grs.; find the specific gravity of the alcohol.

19. A body loses 25 grs. in water, 23 grs. in oil, and 19 grs. in alcohol. Required the specific gravity of the oil and the alcohol.

20. A body weighing 1536 g. weighs in water 1283 g.; what is its specific gravity?

21. Calculate the specific gravity of sea water from the following data.

Weight of bottle empty......................	3.5305 g.
" " filled with distilled water....	7.6722 g.
" " " sea " ...	7.7849 g.

22. Determine the specific gravity of a piece of wood from the following data: Weight of wood in air, 4 g.; weight of sinker, 10 g.; weight of wood and sinker under water 8.5 g.; specific gravity of sinker, 10.5.

23. A piece of a certain metal weighs 3.7395 g. in air; 1.5780 g. in water; 2.2896 g. in another liquid. Calculate the specific gravities of the metal and of the unknown liquid.

24. Find the specific gravity of a piece of glass if a fragment of it weigh 2160 grains in air, and 1511½ grains in water.

25. A lump of ice weighing 8 lbs. is fastened to 16 lbs. of lead. In water the lead alone weighs 14.6 lbs. while the lead and ice weigh 13.712 lbs. Find the specific gravity of the ice.

26. A piece of lead weighing 600 g., weighs 545 g. in water and 557 g. in alcohol. (*a*.) Find the sp. gr. of the lead; (*b*) of the alcohol. (*c*.) Find the bulk of the lead.

27. A person can just lift a 300 pound stone in the water; what is his lifting capacity in the air (specific gravity of stone = 2.5)?

In the next three examples, the weight of the empty flask is not taken into account.

28. A liter flask holds 870 g. of turpentine; required the sp. gr. of the turpentine.

29. A liter flask, containing 675 g. of water, on having its remaining space filled with fragments of a mineral, was found to weigh 1487.5 g.; required the specific gravity of the mineral.

30. A liter flask was four-fifths filled with water; the remaining space being filled with sand the weight was found to be 1350 g.; required the specific gravity of the sand.

31. A weight of 1000 grs. will sink a certain Nicholson's hydrometer to a mark on the rod carrying a pan. A piece of brass plus 40 grs. will sink it to the same mark. When the brass is taken from the pan and placed in the basket, it requires 160 grs. in the pan to sink the hydrometer to the same mark on the rod. Find the specific gravity of the brass.

32. A Fahrenheit's hydrometer, which weighs 2000 grs., requires 1000 grs. in the pan to sink it to a certain depth in water. It requires 3400 grs. in the pan to sink it to the same depth in sulphuric acid. Find the specific gravity of the acid.

33. A certain body weighs just 10 g. It is placed in one of the scale-pans of a balance together with a flask full of pure water. The given body and the filled flask are counterpoised with shot in the other scale-pan. The flask is removed, and the given body placed therein, thus displacing some of the water. The flask being still quite full is carefully wiped and returned to the scale-pan, when it is found that there is not equilibrium. To restore the equilibrium, it is necessary to place 2.5 g. with the flask. Find the specific gravity of the given body.

34. The volume of the earth is 1,082,842,000,000,000 cu. Km. Calculate its weight on the supposition that its average density is 5.6604.

35. A bottle holds 2545 mg. of alcohol (sp. gr. = 0.8095); 42740 mg. of mercury; 5829 mg. of sulphuric acid. Calculate the specific gravities of the mercury and of the acid.

36. A piece of cork weighing 2.3 g. was attached to a piece of iron weighing 38.9 g., both were found to weigh in water 26.2 g., the iron alone weighing 33.9 g. in water. Required the specific gravity of the cork.

37. A piece of wood weighing 300 grs. has tied to it a piece of lead weighing 600 grs.; weighed together in water they weigh 472.5 grs. The specific gravity of lead being 11.35, (*a*) what does the lead weigh in water; (*b*) what is the specific gravity of the wood?

38. Calculate the specific gravity of a mineral water from the following data:

Weight of a bottle empty.................... 14.1256 g.
" " filled with distilled water..111.1370 g.
" " " " mineral " ..111.7050 g.

39. A Fahrenheit's hydrometer weighs 618 grs. It requires 93 grs. in the pan to sink it to a certain mark on the stem. When wiped dry and placed in olive oil it requires only 31 grs. to sink it to the same mark. Find the specific gravity of the oil.

40. A platinum ball weighs 330 g. in air, 315 g. in water and 303 g. in sulphuric acid. Find the specific gravities (*a*) of the ball; (*b*) of the acid. (*c*.) What is the volume of the ball?

41. A hollow ball of iron weighs 1 Kg. What must be its least volume to float on water?

42. A piece of cork weighing 30 g. in air, was attached to 10 cu. cm. of lead. Loss of both in water = 159 g. Required the specific gravity of the cork.

43. A body whose specific gravity = 2.8, weighs 37 g. Required its weight in water.

44. What would a cubic foot of coal (sp. gr. = 2.4) weigh in a solution of potash (sp. gr. = 1.2)?

45. A platinum ball (sp. gr. = 22) weighing 300 g. in air will weigh how much in mercury (sp. gr. = 13.6)?

46. 500 cu. cm. of iron, specific gravity 7.8, floats on mercury; with what force is it buoyed up?

47. An areometer weighing 600 grs. sinks in water displacing a volume = v; in a certain acid, displacing a volume = $\frac{9}{16} v$; find the specific gravity of the acid.

Recapitulation.—In this section we have considered the Definition of Specific Gravity; the Standards agreed upon; the Two Elements in specific gravity problems; the Rule for finding the sp. gr. of Solids heavier than Water; the same for Solids lighter than Water; the same for Liquids; the same for Gases; the construction and methods of using Hydrometers; Tables of specific gravities, and some of the uses that may be made of them.

SECTION IV.

HYDROKINETICS.

254. Velocity of Spouting Liquids.—If a vessel having apertures in the side, similar to the one represented in Fig. 86, be filled with water, the liquid will escape from each of the apertures, but with different velocities. Were it not for the resistance of the air, friction, and the effect of the falling particles, the water issuing at *V* would ascend to the level of the water in the vessel; *i. e.*, the initial velocity of the water at *V* would carry it through the vertical distance *Vh*. But when equal verti-

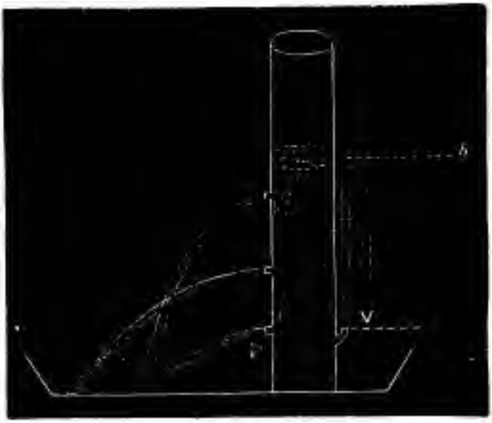


FIG. 86.

cal distances are passed over, the initial velocity of an ascending body is the same as the final velocity of a falling body. (§ 132.) Hence, the velocity of the water as it issues at *V* is the same that it would acquire in freely falling the vertical distance *h V*. This velocity is caused by lateral pressure. This lateral pressure will be the same at *P*, which is at the same distance below the level of the liquid. Therefore, the velocity at *P* will equal the velocity at *V*. Hence the following law: *The velocity of a stream flowing from an orifice is the same as that acquired by a body freely falling from a height equal to the head of the liquid.*

(*a.*) The *head* is the vertical distance from the centre of the orifice to the surface of the liquid.

(*b.*) With what velocity will water issue from an orifice 144.72 ft. below the surface of the liquid?

$$
\begin{aligned}
S &= \tfrac{1}{2}gt^2 && (\S\ 128\ [3].) \\
144.72 &= 16.08t^2 && \therefore\ 9 = t^2. \\
3 &= t. \\
v &= gt. && (\S\ 128\ [1].) \\
v &= 32.16 \text{ ft.} \times 3 = 96.48 \text{ ft. } \textit{Ans.}
\end{aligned}
$$

(*c.*) In the solution above we were obliged to find the number of seconds that would be required for a body to fall a distance equal to the head, before we could use the formula for the velocity. It is desirable, if possible, to shorten this circuitous process from two stages to one. This we may do as follows:

$$S = \tfrac{1}{2}gt^2 \quad \therefore \quad t = \sqrt{\frac{2S}{g}}$$

Substituting this value of t in the formula, $v = gt$,

$$v = g\sqrt{\frac{2S}{g}} = \sqrt{2gS}$$

But h (the head) $= S$. Substituting this value of S in the last equation, we have, for the velocity of streams issuing from orifices, the following formula:

$$v = \left(\sqrt{2gh} = \sqrt{64.32h} =\right) \mathbf{8.02\sqrt{h}}.$$

The value of g being taken in feet, h and v must represent feet also.

(*d.*) With what velocity will water issue from an orifice under a head of 144.72 feet?

$$v = 8.02\sqrt{h}$$

$$v = 8.02\sqrt{144.72} = 8.02 \times 12.03 = 96.48, \text{ the number of feet.}$$

255. Orifice of Greatest Range.—The path of a stream spouting in any other than a vertical direction is the curve called a parabola (§ 135). The range of such a stream will be the greatest when it issues from an orifice midway between the surface of the liquid and the level of the place where the stream strikes. Streams flowing from orifices equidistant above and below this orifice of greatest range will have equal ranges. (See Fig. 86.) The range, in any such case, may be calculated by the laws of projectiles.

(*a.*) Given an aperture four feet below the surface and 20 ft. above the point where the water strikes, to find the range of the jet.

$$v = 8.02\sqrt{h} = 8.02 \times 2 = 16.04 \text{ ft. per second.}$$

$$S = \tfrac{1}{2}gt^2$$

$$20 = 16.08t^2 \quad \therefore \quad t = 1.11 + \text{sec.}$$

$$\text{Range} = 16.04 \text{ ft.} \times 1.11 = 17.8044 \text{ ft.}$$

256. Volume Discharged under a Constant Head.—*To find the volume discharged in a given time under a constant head, multiply the area of the orifice by the velocity, and this product by the number of seconds.*

(*a.*) Suppose that as soon as the water escapes it freezes and retains the form and size given it by the aperture. It will then be evident that the water escaping in one second will form a prism whose section will be the area of the orifice and whose length will be the same as the velocity of the jet. The product of these dimensions will give the volume of the imaginary prism, one of which is formed every second. Care must be had that the velocity and the dimensions of the orifice are of the same denomination. The *theoretical* result computed as above directed, will exceed the amount actually discharged. Why? (See Appendix E.)

257. The Flow of Liquids through Horizontal Pipes.—When liquids from a reservoir are made to flow through pipes of considerable length, *the discharge is far less than that due to the head.* This is chiefly owing to the friction of the liquid particles against the sides of the pipe. A horizontal inch-pipe 200 feet long will not discharge much, if any, more than a quarter as much water as a very short pipe of the same size, the head being the same. Frequent and abrupt bends in the pipe retard the flow, and must be provided for by an increase in the size of the pipe, or an increase of pressure.

258. The Flow of Rivers.—The friction of a stream against its solid bed fortunately retards the velocity of the water. Otherwise the velocity of the current at the mouth of a river, whose head is elevated 1000 feet above its mouth, would be about 170 miles per hour. Such a current would be disastrous beyond description

The ordinary river current is from three to five miles per hour.

259. The Flow of Liquids through Vertical Pipes.—Liquids flowing freely through vertical pipes *exert no lateral pressure.* The liquid will not wholly fill the tube, but will be surrounded by a thin film of air. These air particles will be dragged down by the adhesion of the falling liquid.

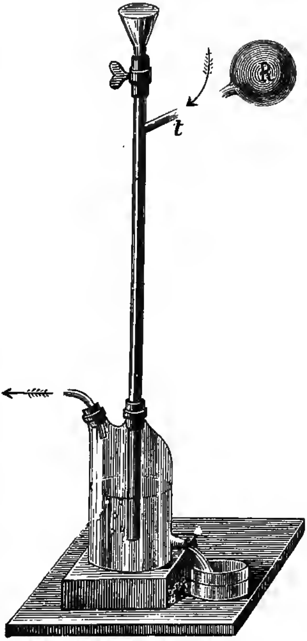


FIG. 87.

(*a.*) If a small tube, *t*, be inserted near the top of the vertical pipe a current of air will be forced through it and down the pipe. This air current may be utilized for blow-pipe and other purposes. With a long discharge pipe, the force with which the air is drawn through *t* may be used to remove the air from a vessel, *R*. The apparatus then becomes a Sprengel's or Bunsen's air-pump. (§§ 290, 291.)

260. Water-Power.—Water may be used to turn a wheel and thus move machinery by its weight, the force of the current, or both. The wheels thus turned are of different kinds; the availability of any one being determined by the nature of the water supply and the work to be done.

(*a.*) The water supply depends upon rains; rains depend upon evaporation; evaporation is produced by solar heat. The energy of water-power is thus traced to the sun as its source.

261. The Overshot Wheel.—In the overshot wheel, the water falls into buckets at the top and, by its weight, aided by the force of the current, turns the wheel. As the buckets are gradually inverted, the water is emptied and the load thus removed from the other side of the wheel. Such wheels require only little water but a considerable fall. It is said that they have been made nearly 100 feet in diameter. The water is led to the top of the wheel by a *sluice*, *v s*.

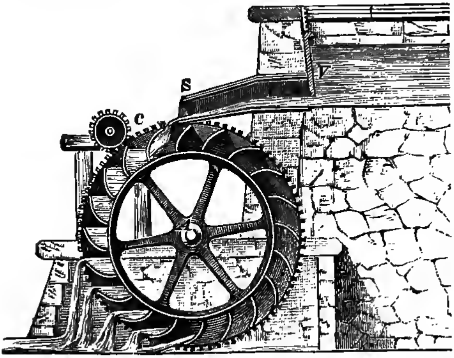


FIG. 88.

262. The Breast Wheel.—In the breast wheel, the water acts upon float boards fixed perpendicular to the circumference. The stream being received at or near the level of the axis, both the weight of the water and the force of the current may be turned to account.

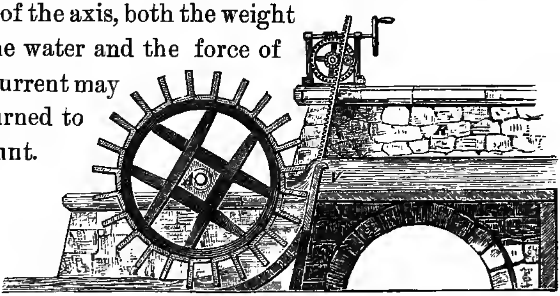


FIG. 89.

263. The Undershot Wheel.—In the undershot wheel, the stream strikes, near the bottom of the wheel, against a few float boards, which are more or less submerged, and thus acts by the force of the current.

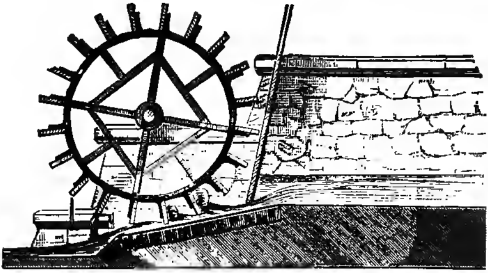


FIG. 90.

Note.—In point of efficiency, these wheels rank in the order above given, utilizing from 80 to 25 per cent. of the total energy (*e. g.*, foot-pounds) of the stream.

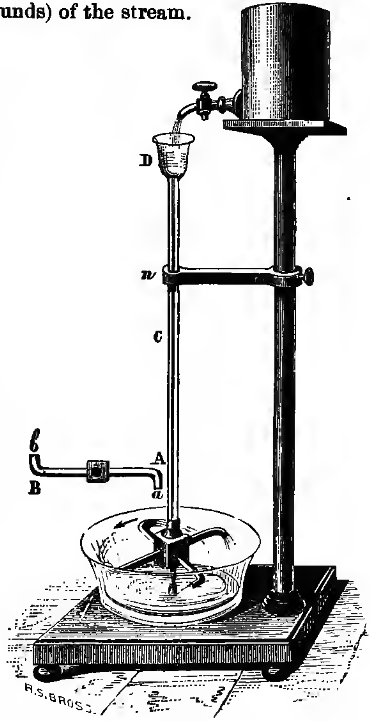


FIG. 91.

264. The Reaction Wheel. — The reaction wheel is well illustrated by Barker's Mill, represented in Fig. 91. It consists essentially of a vertical tube connecting with horizontal tubular arms at the bottom. The ends of these arms are bent in the same direction, and are open at their ends. The apparatus is supported on a pivot so as to move freely. Water is poured into the upper end of the vertical cylinder, and escapes through the openings *a* and *b*, at the bent ends of the arms. The wheel revolves in a direction opposite to that of the water jets. The principle involved was explained in § 230. (See Appendix F.)

265. The Turbine Wheel.—The turbine wheel, of which there are many varieties, is the most effective water-wheel yet known, utilizing, in some cases, 85 per cent. of the total energy of the stream.

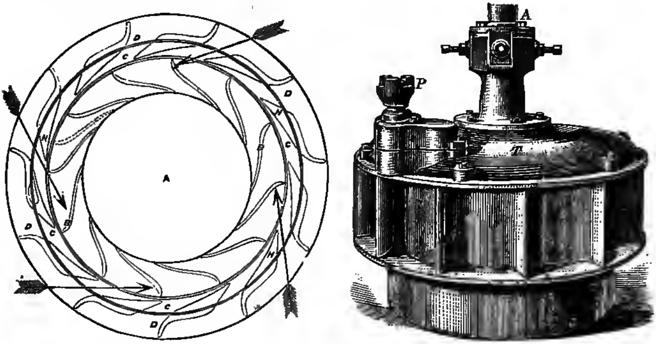


FIG. 92.

(*a.*) Fig. 92 represents one form in perspective and in horizontal section through the centre of the wheel and case complete. The wheel B and the enclosing case D are placed on the floor of a penstock wholly submerged in water, under the pressure of a considerable head. The water enters, as shown by the arrows, through openings in D, which are so constructed that it strikes the buckets of B in the direction of greatest efficiency. After leaving the buckets, the "dead-water" escapes from the central part of the wheel, sometimes by a vertical draft tube, best made of boiler-iron. The weight of the water in this tube increases the velocity with which the water strikes the buckets. A central shaft, A, is carried by the wheel and communicates its motion to the machinery above. The wheel itself rests upon a central pivot carried by cross-arms from the bottom of the outer case. The case D is covered with a top T, which protects the wheel from the vertical pressure of the water. The axis of the wheel passes through the centre of this cover. The openings by which the water passes to the wheel are called chutes. Sometimes a cylindrical collar, C, is placed between the wheel B and the outer case D. This collar, called a register gate, may be turned about its axis by the action of a pinion, P, upon teeth placed upon the circumference of C. By means of the register gate, the size of the chute may be reduced and the amount of water used thus diminished. The water passages, to and from the wheel, should be of such a size that the velocity of the water running through them shall not exceed one and a half feet per second.

266. Lateral Pressure of Running Water.—If water could flow through a pipe unimpeded ($v = 8.02 \sqrt{h}$), there would be no lateral pressure. But as the velocity is lessened by friction and other causes, this lateral pressure begins to be felt; when the velocity is destroyed, lateral pressure has its full force again. Thus, a pipe is less likely to burst when carrying running water than when filled with water at rest.

267. Bursting Pressure.—If a current of water flowing in a pipe be suddenly stopped, much of its momentum will be changed to lateral or bursting pressure. This takes place whenever the faucet of a water-pipe is suddenly closed. Plumbers frequently leave the ends of such pipes in a vertical position so that a quantity of air may be confined between the closed end of the pipe and the water below. This air by its elasticity acts as a pad or cushion, thus lessening the suddenness of the shock and preventing accidents.

(*a*.) This principle is practically applied in the "hydraulic ram," a contrivance by which the impulse of running water when suddenly checked may be used to raise a part of the water through a vertical distance greater than the head.

EXERCISES.

1. A stream of water issues from an orifice at the bottom of a vessel containing water 169 feet deep. Give the velocity of the stream?

2. How much water issues in one hour from the orifice in the bottom of a vessel in which the water always stands 12 feet high, the orifice being $\frac{1}{10}$ of a square inch?

3. How much water per hour will be delivered from an orifice of 2 inches area, 25 feet below the surface of a tank kept full, no allowance being made for friction, etc.?

4. From an orifice, water spouts with a velocity of 96.24 feet. What is the head? *Ans.* 144 ft.

5. An orifice is 16.08 feet above a horizontal floor. Water spouts to the distance of 80.2 feet. Required the head.

6. Determine the formula for the velocity of spouting liquids, using meters instead of feet. *Ans.* $v = 4.427\sqrt{h}$.

7. A stream of water issues from an orifice under a head of 25 meters. Find the velocity of the stream.

8. How many liters of water will flow through an opening of 10 sq. cm. in 20 seconds, the head being kept at 36 m.? *Ans.* 531.24 l.

9. How long will it take for 442,700 cu. cm. of water to escape through a hole 1 centimeter square and 100 meters below the surface of the liquid?

10. How long will it take to empty a tank having a base 3 m. by 4 m. the water being 25 m. deep, by means of a sq. cm. hole in its bottom?

Recapitulation.—In this section we have considered the **Velocity** of spouting liquids; the orifice of **Greatest Range**; the method of computing the **Volume discharged** by an orifice when the **Head** is constant; the flow of liquids through **Pipes** and **Rivers**; the uses of **Water-power**; the five kinds of **Water-wheels**; the **Lateral Pressure** of running water; the **Bursting Pressure** when the current is suddenly stopped.

REVIEW QUESTIONS AND EXERCISES.

1. (*a.*) Define Physics. (*b.*) Define and illustrate four universal properties of matter.

2. (*a.*) What is the difference between momentum and energy? (*b.*) Find the momentum and (*c.*) kinetic energy of a 15 lb. ball moving fifty feet per second.

3. (*a.*) Give the third law of motion and illustrate it. (*b.*) Give the law of reflected motion.

4. (*a.*) What would a 1470 lb. ball weigh at 10,000 miles above the earth? (*b.*) Give the law that you use.

5. (*a.*) How far will a body fall during the fourth second? (*b.*) How far in four seconds? (*c.*) What will be its final velocity?

6. The crank of an endless screw whose threads are an inch apart describes a circuit of 72 inches. The screw acts on the toothed edge of a wheel whose circumference is 90 inches and that of its axle 12 inches. On the axle is wound a cord which acts on a set of pulleys three in each block, the force of which pulleys is exerted on the wheel of a wheel and axle, the wheel being 4 feet and the axle 8 inches in diameter. What weight on the axle will be lifted by a power of 30 lbs. at the crank, allowing for a loss of one-third by friction?

7. (*a.*) What is the length of a pendulum making 25 vibrations a minute? (*b.*) How many vibrations are made per minute by a pendulum 25 inches long?

8. (*a.*) What is a horse-power? (*b.*) A unit of work? (*c.*) If a two horse-power engine can just throw 1056 lbs. of water to the top of a steeple in 2 minutes, what is the height of the steeple?

9. (*a.*) What are the laws of machines? (*b.*) The facts concerning friction? (*c.*) What is a lever? (*d.*) Figure a lever of each kind. In a lever of the second kind the power is $4\frac{1}{2}$, the weight is $40\frac{1}{2}$, the distance of the power from the weight is 18 in. (*e.*) What is the length of the lever? (*f.*) What the length of the short arm?

10. If the diameters of the wheel and of the axle of a wheel and axle are respectively 60 in. and 6 in., and the power is 150 lbs., what weight will be sustained?

11. (*a.*) Draw a system of 3 fixed and 2 movable pulleys. (*b.*) If the power be 90 and the friction one-third, what weight can be raised?

12. (*a.*) A weight of 12 pounds, hanging from one end of a five foot lever considered as having no weight, balances a weight of 8 pounds at the other end. Find how far the fulcrum ought to be moved for the weights to balance when each is increased by two pounds. (*b.*) Give the law for the screw?

13. A capstan, 14 inches in diameter, has four levers each 7 feet long. At the end of each lever a man is pushing with a force of 42 pounds. What is the effect produced, one-fourth of the energy expended being lost by friction?

CHAPTER V.

PNEUMATICS.

SECTION I.

THE ATMOSPHERE AND ATMOSPHERIC PRESSURE.

268. What is Pneumatics?—*Pneumatics is that branch of Physics which treats of aeriform bodies, their mechanical properties, and the machines by which they are used.*

269. Tension of Gases.—*However small their quantity, gases always fill the vessels in which they are held.* If a bladder or India rubber bag, partly filled with air, and having the opening well closed, be placed under the receiver of an air-pump, the bladder or bag will be fully distended, as shown in the figure, when the air surrounding the bladder is pumped out. The flexible walls are *pushed out* by the impact of the moving molecules confined within. (See § 62.)

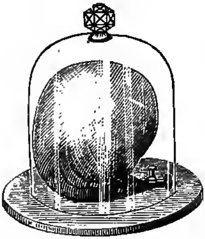


FIG. 93.

270. The Type.—As water was, for obvious reasons, taken as the type of liquids, so *atmospheric air will be* *taken as the type of aeriform bodies.* Whatever mechanical properties are shown as belonging to air may be understood as belonging to all gases.

271. The Aerial Ocean.—Air is chiefly a mixture of two gases, oxygen and nitrogen, in the proportions of one to four by volume. It is believed that the atmosphere at its upper limit presents a *definite surface* like that of the sea; that disturbing causes produce waves there just as they do on the sea, but that, by reason of greater mobility and other causes, the waves on the surface of this aërial ocean are much larger than any ever seen on the surface of the liquid ocean. The depth of this aërial ocean has been variously estimated at from fifty to two hundred miles.

272. Weight of Air.—Being a form of matter, air has weight. This may be shown by experiment. A hollow globe of glass or metal, having a capacity of several liters and provided with a stop-cock, is carefully weighed on a delicate balance. The air is then removed from the globe by an air-pump, the stop-cock closed, and the empty globe weighed carefully. The second weight will be less than the first, the difference between the two being the weight of the air removed. Under ordinary conditions a cubic inch of air weighs about 0.31 grains; a liter of air weighs about 1.293 *g.*, being thus about $\frac{1}{770}$ as heavy as water. (See Appendix G.)

273. Atmospheric Pressure.—Having weight, such a quantity of air must exert a great pressure upon the surface of the earth and all bodies found there. This atmospheric pressure necessarily decreases as we ascend from the earth's surface. For any surface, at any elevation, the upward, downward, or lateral pressure may be computed in the same way as for liquids (§§ 226, 228 and 231). Owing to the great compressibility of aëriform bodies, the lower layers of the atmosphere are much more dense than the upper ones, but density and pressure alike are constant in value throughout any horizontal layer. The weight of a column of air one inch square extending from the sea-level to the upper limit of the atmosphere is about fifteen pounds; a similar column, a *cm.* square, weighs about 1 *Kg.* We express this by saying that *the atmospheric pressure at the sea-level is fifteen pounds to the square inch,* or 1 *Kg.* to the *sq. cm.* Several illustrations of atmospheric pressure will be given after we have considered the air-pump.

274. Torricelli's Experiment.—The intensity of this pressure may be measured as follows:—Take a glass tube a yard long, about a quarter of an inch in internal diameter. Close one end and fill the tube with mercury. Cover the other end with the thumb or finger and invert the tube, placing the open end in a bath of mercury. Upon removing the thumb, the mercury will sink, oscillate, and finally come to rest at a height of about 30 inches, or 760 *mm.*, above the level of the mercury in the bath. This historical experiment was first performed in 1643, by Torricelli, a pupil of Galileo. The apparatus used, when properly graduated, becomes a barometer.

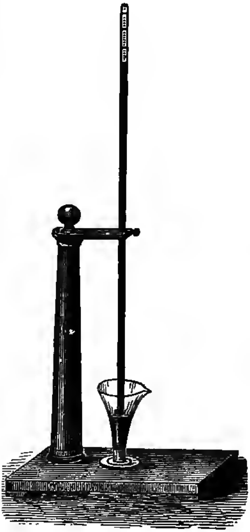


FIG. 94.

275. What Supports the Mercury Column?—To answer this very important question, consider the horizontal layer of mercury molecules in the tube at the level of the liquid in the bath. Under ordinary circumstances, they would hold their position by virtue of the tendency of liquids to seek their level. But in this case, they hold it against the downward pressure caused by the weight of the mercury column above, which is equivalent to fifteen pounds to the square inch. Being in a condition of equilibrium, they must be acted upon by an upward pressure of fifteen pounds to the square inch. It is evident that the pressure of the mercury in the bath is not able to do this work, its powers being fully tasked in supporting the mercury in the tube up to the level of the particular molecules now under consideration. This upward pressure then must be due to some force acting upon the surface of the mercury, and transmitted undiminished by that liquid. *The only force, thus acting, is atmospheric pressure,* which is thus measured. The original column of thirty-six inches fell because its weight was greater than the opposing force. As it fell, its weight diminished, continuing to do so until an equality of opposing forces produced equilibrium. (See Appendix H.)

276. Pascal's Experiments.—Pascal confirmed Torricelli's conclusions by varying the conditions. He had the experiment repeated on the top of a mountain and found that the mercury column was three inches shorter, showing that as the weight of the atmospheric column diminishes, the supported column of mercury also diminishes. He then took a tube forty feet long, closed at one end. Having filled it with water, he inverted it over a water bath. *The water in the tube came to rest at a height of 34 feet.* The water column was 13.6 times as high as the mercury column, but as the specific gravity of mercury is 13.6, the weights of the two columns were equal. Experiments with still other liquids gave corresponding results, all of which strengthened the theory that the supporting force is due to the weight of the atmosphere, and left no doubt as to its correctness.

277. Pressure Measured in Atmospheres.—A gas or liquid which exerts a force of fifteen pounds upon a square inch of the restraining surface is said to exert a pressure of one atmosphere. A pressure of 60 pounds to the square inch, or 4 *Kg.* to the *sq. cm.*, would be called a pressure of four atmospheres.

278. The Accuracy of a Barometer.—The accompanying figure represents the simplest form of the barometer. The instrument's accuracy depends upon the purity of the mercury, the accuracy of measuring the vertical distance from the level of the liquid in the cistern to that in the tube, and the freedom of the space at the top of the tube from air and moisture. In delicate observations allowance must be made for differences of temperature. In technical language, "The barometric reading is corrected for temperature."

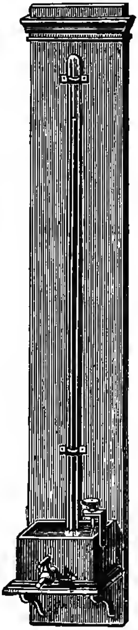


FIG. 95.

279. The Utility of a Barometer.—This instrument's efficiency depends upon the fact that variations in atmospheric pressure produce corresponding variations in the height of the barometer column. It is used to determine the height of places above the sea-level, foretell storms, etc. When, at a given place, the "barometer falls," a storm is generally looked for. Sometimes the storm does not come, and faith in the accuracy of the instrument is shaken. But, in fact, the barometer did not announce a coming storm; *it did proclaim a diminution of atmospheric pressure from some cause or other.* Its declarations are perfectly reliable; inferences from those declarations are subject to possible error.

280. The Aneroid Barometer.—This instrument consists of a cylindrical box of metal with a top of thin, elastic, corrugated metal. The air is removed from the box. The top is pressed inward by an increased atmospheric pressure; whenever the atmospheric pressure diminishes, it is pressed outward by its own elasticity aided by a spring beneath. These movements of the cover are transmitted and multiplied by a combination of delicate levers. These levers act upon an index which is thus made to move over a graduated scale. Such barometers are much more easily portable than the mercurial instruments. They are made so delicate that they show a difference in atmospheric pressure when transferred from an ordinary table to the floor. Their very delicacy involves the necessity for careful usage or frequent repairs.

FIG. 96.

281. The Baroscope.—Air, having weight, has buoyant power. The Principle of Archimedes (§ 238) applies to gases as well as to liquids. From this it follows that the weight of a body in air is not its true weight, but that it is less than its true weight by exactly the weight of the air it displaces. This principle is illustrated by the baroscope, which consists of a scale-beam supporting two bodies of very unequal size (as a hollow globe and a lead ball), which balance one another in the air. If the apparatus thus balanced in the air be placed under the receiver of an air-pump, and the air exhausted, the globe will descend, thus seeming to be heavier than the lead ball which previously balanced it. Is the globe actually heavier than the lead, or not?

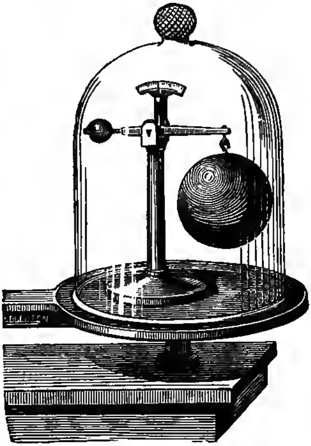


FIG. 97.

EXERCISES.

1. Give the pressure of the air upon a man the surface of whose body is 14½ square feet.

2. A soap-bubble has a diameter of 4 inches; give the pressure of the air upon it. (See Appendix A).

3. What is the weight of the air in a room 30 by 20 by 10 feet?

4. What will be the total pressure of the atmosphere on a decimeter cube of wood when the barometer stands 760 mm.?

5. How much weight does a cubic foot of wood lose when weighed in air?

6. (*a.*) What is the pressure on the upper surface of a Saratoga trunk 2½ by 3½ feet? (*b.*) How happens it that the owner can open the trunk?

7. When the barometer stands at 760 mm. what is the atmospheric pressure per sq. cm. of surface? *Ans.* 1033.6 g.

Note.—In round numbers, atmospheric pressure at the sea-level is called 15 lbs. to the sq. in., or 1 kilogram to the sq. cm.

8. A certain room is 10 m. long, 8 m. wide and 4 m. high. (*a.*) What weight of air does it contain? (*b.*) What is the pressure upon its floor? (*c.*) Upon its ceiling? (*d.*) Upon each end? (*e.*) Upon each side? (*f.*) What is the total pressure upon the six surfaces? (*g.*) Why is not the room torn to pieces?

9. An empty toy balloon weighs 5 g. When filled with 10 *l.* of hydrogen, what load can it lift? (See Appendix, G.)

Recapitulation.—In this section we have considered the definitions of **Pneumatics** and **Tension**; the **Aerial Ocean** in which we live; the mechanical **Properties of Air**; the weight of air giving rise to **Atmospheric Pressure**; a famous experiment by **Torricelli**, and the explanation thereof; **Pascal's** experiments and the conclusion they confirmed; the **Barometer**; the **Aneroid** barometer; the **Baroscope**.

SECTION II.

THE RELATION OF TENSION AND VOLUME TO PRESSURE.

282. Tension of Gases.—If a glass flask, provided with a stop-cock, be closed under an atmospheric pressure which supports a mercury column of 30 inches, the atmospheric pressure from without is exactly balanced by the tension (§ 269) of the air within. If it be closed under a barometric pressure of 28 inches, this equality of the two pressures will continue. If the flask be closed when the surrounding air is subjected to a pressure of two or three atmospheres, the equality will still continue. In none of these cases will the glass be subjected to any strain because of the air within or without. *The tension of aeriform bodies supports the pressure exerted upon them, and is equal to it.*

283. Experimental Illustrations of Tension.—(1.) The tension of confined air is well illustrated by the common pop-gun It is also well illustrated by the common experiment with bursting squares. These "squares" are made of *thin* glass, are about two or three inches on each edge, and are hermetically sealed under the ordinary atmospheric pressure. The tension of the air within, acting with equal intensity against the atmospheric pressure from without, the frail walls remain uninjured. When, however, the "square" is placed under the receiver of an air-pump and the external pressure removed, the tension of 15 pounds to the square inch is sufficient to burst the walls outward.

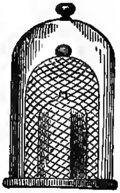


FIG. 98.

(2.) Half fill a small bottle with water, close the neck with a cork through which a small tube passes. The lower end of this tube should dip into the liquid; the upper end should be drawn out to a smaller size. Apply the lips to the upper end of the tube, and force air into the bottle. Notice, describe, and explain what takes place.

(3.) Place the bottle, arranged as above described, under the receiver of an air-pump, and exhaust the air from the receiver. Water will be driven in a jet from the tube. Explain.

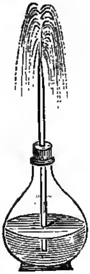


FIG. 99.

284. Mariotte's Law.—*The temperature remaining the same, the volume of a given quantity of gas is inversely as the pressure it supports.*

285.—Experimental Verification of Mariotte's Law.—This law may be experimentally verified with Mariotte's tube. It consists of a long glass tube bent as shown in Fig. 100, the long arm being open and the short arm closed. A small quantity of mercury is poured into the tube, so that the two mercurial surfaces are in the

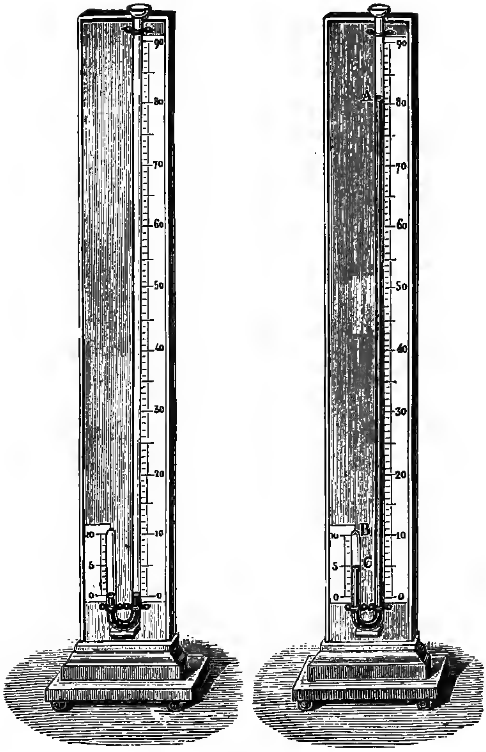


FIG. 100.

same horizontal line. By holding the tube nearly level, bubbles of air may be passed into the short arm or from it until the desired result is secured. The air in the short arm will then be under an ordinary atmospheric pressure. As more mercury is poured into the long arm the confined air will be compressed.

(*a.*) When the vertical distance between the levels of the mercury in the two arms is one-third the height of the barometric column at the time and place of the experiment, the pressure upon the confined air will be $\frac{4}{3}$ atmospheres; the tension of the confined air just supports this pressure and must therefore be $\frac{4}{3}$ atmospheres. The volume of the confined air is only $\frac{3}{4}$ what it was under a pressure of one atmosphere. If more mercury be poured into the long arm until the vertical distance between the two mercurial surfaces is one-half the height of the barometric column, the pressure and tension will be $\frac{3}{2}$ atmospheres; the volume of the confined air will be $\frac{2}{3}$ what it was under a pressure of one atmosphere. When mercury has been poured into the long arm until the vertical distance *CA* is equal to the height of the barometric column, the pressure and tension will be two atmospheres, and the volume of the confined air will be one-half what it was under a pressure of one atmosphere. The law has been thus "verified" up to 27 atmospheres, notwithstanding which it is not considered rigorously exact. The deviation from exactness, however, can be detected only by measurement of great precision.

286. The Rule Works both Ways.—The law holds good for pressures of less than one atmosphere, for rarefied air as well as for compressed air. To show that this is true, nearly fill a barometer tube with mercury and invert it over a mercury bath held in a glass tank as shown in the figure. Lower the tube into the tank until the mercury levels within the tube and without it are the same. The air in the tube is confined under a pressure of one atmosphere. Note the volume of air in the barometer tube. Raise the tube until this volume is doubled. The vertical distance between the two mercurial surfaces will be found to be half the height of the barometric column. The confined portion of air, which is now subjected to the pressure of half an atmosphere, occupies twice the space it

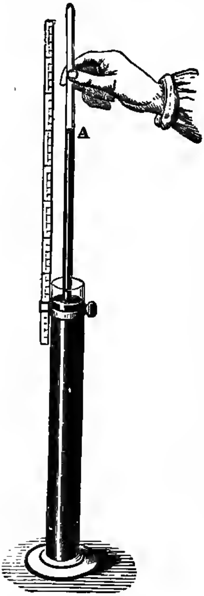


FIG. 101.

did under a pressure of one atmosphere. And so on. It may be more convenient to have the barometer tube open at both ends, the upper end being closed with the thumb or finger before lifting.

287. A Summing Up.—From the foregoing experiments we have a right to conclude that *the density and tension of a given quantity of gas are directly, and that its volume is inversely, as the pressure exerted upon it.* Representing the volumes of the same quantity of gas by V and v, and the corresponding pressures and densities by P and p, D and d, our conclusion may be algebraically expressed as follows:

$$\frac{V}{v} = \frac{p}{P} = \frac{d}{D}.$$

EXERCISES.

1. Under ordinary conditions, a certain quantity of air measures one liter. Under what conditions can it be made to occupy (*a.*) 500 cu. cm.? (*b.*) 2000 cu. cm.?

2. Under what circumstances would 10 cu. inches of air at the ordinary temperature weigh 31 grains?

3. Into what space must we compress (*a.*) a liter of air to double its tension? (*b.*) A liter of hydrogen?

4. A barometer standing at 30 inches is placed in a closed vessel. How much of the air in the vessel must be removed that the mercury may fall to 15 inches?

5. A vertical tube, closed at the lower end, has at its upper end a frictionless piston which has an area of one sq. inch. The weight of this piston is five pounds. (*a.*) What is the tension of the air in the tube? (*b.*) If the piston be loaded with a weight of ten pounds, what will be the tension?

6. When the barometer stands at 28½ inches, the mercury is at the same level in both arms of a Mariotte's tube. The barometer rises and the difference in the two mercurial surfaces of the Mariotte's tube is half an inch. (*a.*) In which arm is it the higher? (*b.*) Why?

7. Eight grains of air are enclosed in a rigid vessel of such size that the tension is $16\frac{1}{2}$ pounds per square inch. What will be the tension if three more grains of air be introduced?

Recapitulation.—In this section we have considered the Equality of tension and pressure, with several Experimental Illustrations; Mariotte's Law; the Verification of that law for Compressed and for Rarefied Gases; a brief Conclusion from the teachings of these experiments.

SECTION III.

AIR-PUMPS.—LIFTING AND FORCE-PUMPS.—SIPHON.

288. The Air-Pump.—*The air-pump is an instrument for removing air from a closed vessel.* The essential parts are shown in section by Fig. 102; the complete instrument, as made by Ritchie, is represented by Fig. 103.

The closed vessel R is called a receiver. It fits accurately upon a horizontal plate, through the centre of which is an opening communicating, by means of a bent tube, t, with a cylinder, C. An accurately fitting piston moves in this cylinder. At the junction of the bent tube with the cylinder, and in the piston, are two valves, v and v', opening from the receiver but not toward it. The tension of the air in R, and the pressure of the air upon the valves, are equal. When the piston is raised, v' closes and the atmospheric pressure is removed from v. The tension of the air in R opens v. By virtue of its power of indefinite

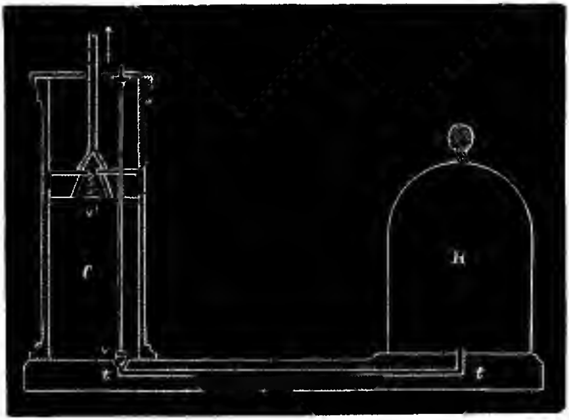


FIG. 102.

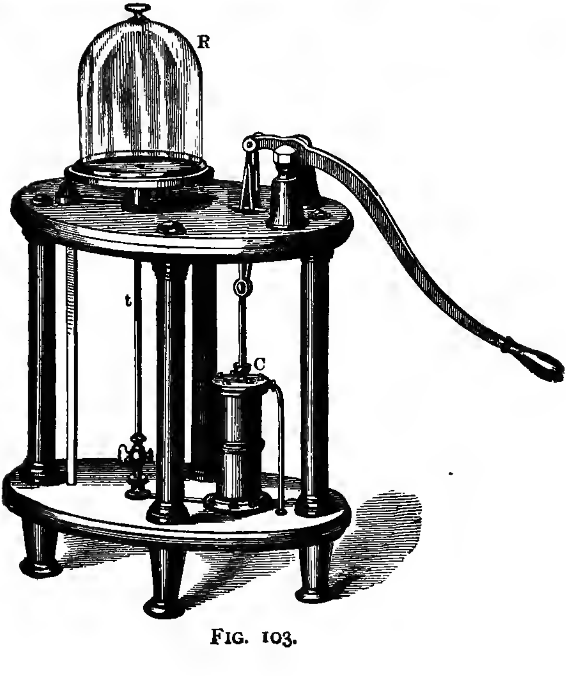


FIG. 103.

expansion, the air which, at first, was in R and t, now fills R, t, and C. When the piston is pushed down, v closes, v' opens, and the air in C escapes from the apparatus.

(a.) The lower valve v is sometimes supported, as shown in Fig 102, by a metal rod which passes through the piston. This rod works tightly in the piston, and is thus raised when the piston is raised, and lowered when the piston is lowered. A button near the upper end of this rod confines its motion within very narrow limits, allows v to be raised only a little, and compels the piston, during most of the journeys to and fro, to slide upon the rod instead of carrying the rod with it.

289. Degrees and Limits of Exhaustion.—Suppose that the capacity of R is four times as great as that of C. (The capacity of t may be disregarded.) Suppose that R contains 200 parts of air (*e. g.*, 200 grains), and C, 50 parts. After lifting the piston the first time, there will be 160 grains $(= 200 \times \frac{4}{5})$ of air in R, and 40 grains $(200 \times \frac{1}{5})$ in C. After the second stroke there will be 128 grains $[= 160 \times \frac{4}{5} = 200 \times \frac{4}{5} \times \frac{4}{5} = 200 \times (\frac{4}{5})^2]$ of air in R, and 32 grains in C. After n upward strokes, $200 \times (\frac{4}{5})^n$ grains of air will remain in the receiver. Evidently, therefore, *we never can, by this means, remove all the air which R contains,* although we might continually approach a perfect vacuum, if this were the only obstacle. It requires an exceedingly good air-pump to reduce the tension of the residual air to $\frac{1}{50}$ inch of mercury. This limit is due to several causes, among which may be mentioned the leakage at different parts of the apparatus, the air given out by the oil used for lubricating the piston, and the fact that there is a space at the bottom of the cylinder untraversed by the piston.

290. Sprengel's Air-Pump.—This instrument is used to apply the principles set forth in § 259 to the exhaustion of small receivers. The liquid used is mercury. The vertical pipe, below the arm *t* (Fig. 87), must be longer than the barometer column (six feet is a common length), and have a diameter of not more than $\frac{1}{10}$ inch. The mercury is admitted by large drops, which, filling the pipe, act as valves and in their fall force out successive quantities of air before them.

(*a.*) With such an instrument, it requires about half an hour to exhaust a half liter receiver, but the average result attainable is a tension of about one-millionth atmosphere or 0.00003 inch of mercury. By this means a tension of only $\frac{1}{18000000}$ atmosphere has been secured. The mercury acts as a dry, frictionless, perfectly fitting, self-adjusting piston. Special precautions must be taken to make the connection air-tight. The only work of the operator is to carry the mercury from the cistern at the foot of the fall tube to the funnel at the top.

291. Bunsen's Air-Pump.—In Bunsen's air-pump the principle is the same, but the liquid used is water, and the length of the vertical pipe at least thirty-four feet. Such an air-pump may be easily provided in a laboratory where the waste-pipe of the sink has the necessary vertical height. The tube *t* (see Fig. 87) being connected with the receiver, has its free end inserted in the waste-pipe a little way below the sink. A stream of water properly regulated, flowing into the sink, completes the apparatus.

292. The Condenser.—*The condenser is an instrument for compressing a large amount of air into a closed vessel.* It differs from the air-pump, chiefly, in that *its valves open toward the receiver.* The cylinder is generally attached directly to the stop-cock of the receiver. Its operation will be readily understood. Sometimes the upper valve, *v′*, instead of being placed in the piston, is placed in a tube opening from the side of the cylinder below the piston. By connecting this lateral tube with a reservoir containing any gas, the gas may be drawn from the reservoir and forced into the receiver. When thus made and used, the instrument is called a *transferrer* (Fig. 104).

Note.—The pupil will notice that in the case of the air-pump, the condenser, the transferrer, and the lifting and force pumps to be subsequently considered, the valves open in the direction in which the fluid is to move.

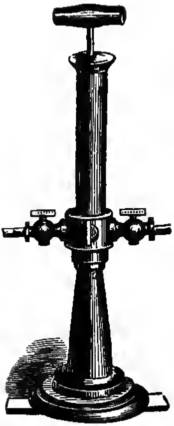


FIG. 104.

293. Experiments. — A person having an air-pump has the means of performing almost numberless experiments, some amusing and all instructive. Other experiments, which may be performed without such apparatus, have been purposely deferred until now. The pupil should explain each experiment.

(1.) The pressure of the atmosphere, which is transmitted in all directions, may be illustrated by filling a tumbler with water, placing a slip of thick paper over its mouth and holding it there while the tumbler is inverted; the water will be supported when the hand is removed from the card.

(2.) Plunge a small tube, or a tube having a small opening at the lower end, into water, cover the upper end with the finger and lift it from its bath. The water is kept in the tube by atmospheric pressure. Remove the finger, and the downward pressure of the atmosphere, which was previously cut off, will counterbalance the upward pressure and the water will fall by its own weight. Such a tube, called a *pipette,* is much used for transferring small quantities of liquids from one vessel to another. The pipette is often graduated.

(3.) *The "Sucker"* consists of a circular piece of thick leather with a string attached to its middle. Being soaked thoroughly in water it is firmly pressed upon a flat stone to drive out all air from between the leather and the stone. When the string is pulled gently there is a tendency toward the formation of a vacuum between the leather and the stone. The stone is now pushed upward with a force of 15 lbs. for every square inch of its lower surface (§ 273.) It is pressed *downward* with a force of 15 lbs. upon each square inch of its upper surface *not covered by the "sucker."* The downward atmospheric pressure upon the leather is sustained by the string. This difference between the upward and downward atmospheric pressures *upon the stone* may be greater than the gravity of the stone. Then we say that the stone is pulled up by the "sucker;" in reality the stone is *pushed up* by the air.

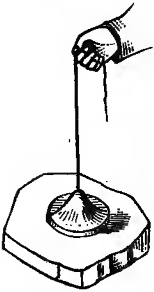


FIG. 105.

(4.) *The hand-glass* is a receiver open at both ends. The lower end fits accurately upon the plate of the air-pump. (It is well to smear the plate with tallow in this and similar experiments.) The hand is to be placed over the other end. When the pump is worked, the pressure of the atmosphere is felt, and the hand can be removed only by a considerable effort. The appearance of the palm of the hand at the end of this experiment is due to the tension of the air within the tissues of the hand.

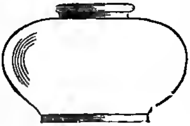


FIG. 106.

(5.) Repeat the experiment described in § 269.

(6.) Over the upper end of a cylindrical receiver, tie tightly a wet bladder, and allow it to dry. Then exhaust the air. The bladder will be forced inward, bursting with a loud noise.

FIG. 107.

(7.) Replace the bladder with a piece of thin india-rubber cloth. Exhaust the air. The cloth will be pressed inward and nearly cover the inner surface of the receiver. The hand-glass, used in experiment (4), will answer for the two experiments last given, by placing the small end upon the pump-plate.

(8.) Review the experiments mentioned in § 283.

(9.) *The "fountain in vacuo"* consists of a glass vessel through the base of which passes a tube terminating in a jet within, and provided with a stop-cock and screw without. By means of the screw it may be attached to the air-pump and the air exhausted. Remove the air, close the stop-cock, place the lower end of the tube in water, open the stop-cock; a beautiful fountain will be produced (Fig. 109).

(10.) *The mercury shower* apparatus consists of a cup through the bottom of which passes a plug of oak or other porous wood. Place the cup upon the *hand-glass* with a tumbler below; pour some mercury into the cup; exhaust the air, and the atmospheric pressure will force the mercury through the pores of the wood.

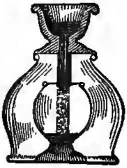


FIG. 108.

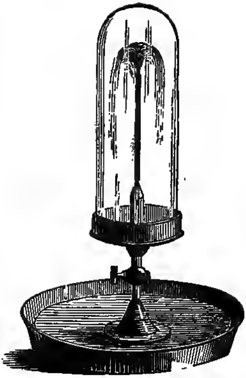


FIG. 109.

(11.) *The weight-lifter* (Fig. 110) is an apparatus by means of which the pressure of the atmosphere may be made to lift quite a heavy weight. It consists of a stout glass cylinder, *C*, supported by a frame and tripod. Within the lower part of the cylinder is a closely fitting piston from which the weight is hung. A brass plate is ground to fit accurately upon the top of the cylinder. This plate is perforated and a flexible tube, *B*, connects the cylinder with an air-pump. When the air is exhausted from the cylinder, the atmospheric pressure on the lower surface of the piston raises the piston and supported weight the length of the cylinder.

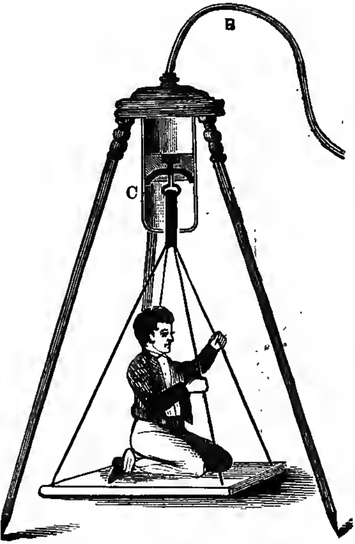


FIG. 110.

(12.) *The Magdeburg hemisnheres* are made of metal. They are hollow, and generally three or four inches in diameter. Their edges are provided with projecting lips which fit one over the other. These edges fit one another air-tight; the lips prevent them from moving *sidewise.* The edges being greased and placed together, the air is exhausted from the hollow globe through a tube provided with a stop-cock and screw. When the air has been pumped out, close the stop-cock, remove the hemispheres from the pump, and screw a convenient handle upon the lower hemisphere, the upper one being provided with a permanent handle. It will be found that a considerable force is necessary to pull the hemispheres asunder. This force is equal to the atmospheric pressure upon the circular area inclosed by the edges of the hemispheres. If this area be ten square inches it will require a pull of 150 pounds to separate the hemispheres.


FIG. 111.

(13.) Partly fill two bottles with water. Connect them by a bent tube which fits closely into the mouth of one and loosely into the mouth of the other. Place the bottles under the receiver and exhaust the air. Water will be driven from the closely stoppered bottle into the other. Readmit air to the receiver and the water thus driven over will be forced back.

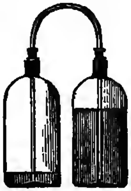


FIG. 112.

294. The Lifting-Pump.

—The lifting-pump consists of a cylinder or barrel, piston, two valves, and a suction pipe, the lower end of which dips below the surface of the liquid to be raised. The arrangement is essentially the same as in the air-pump. As the piston is worked, the air below it is gradually removed. The downward pressure on the liquid in the pipe being thus removed, *the transmitted pressure of the atmosphere, exerted upon the surface of the liquid, pushes the liquid up through*

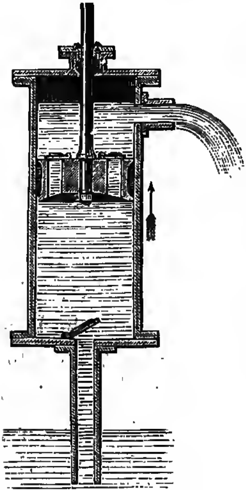


FIG. 113.

the suction pipe and the lower valve into the barrel. When the piston is again pressed down, the lower valve closes, the reaction of the water opens the piston valve, the piston sinking below the surface of the liquid in the barrel. When next the piston is raised, it lifts the water above it toward the spout of the pump. At the same time, atmospheric pressure forces more liquid through the suction pipe into the barrel.

295. Notes and Queries.—The cistern or well containing the liquid must not be cut off from atmospheric pressure, *i. e.*, must not be made air-tight. Why? For water pumps, the suction pipe must not be more than 34 feet high. Why? Owing to mechanical imperfections chiefly, the practical limit of the water pump is 28 vertical feet. As the lifting of the liquid above the piston does not depend upon atmospheric pressure, water may be raised from a very deep well by placing the barrel, with its piston and valves, within 28 feet of the surface of the water, and providing a vertical discharge pipe to the surface of the ground. The piston-rod may work through this discharge pipe. Deep mines are frequently drained by using a series of pumps, one above the other, the handles (levers) of which are worked by a single vertical rod. The lowest pump empties the water into a reservoir, from which the second pump lifts it to a second reservoir, and so on.

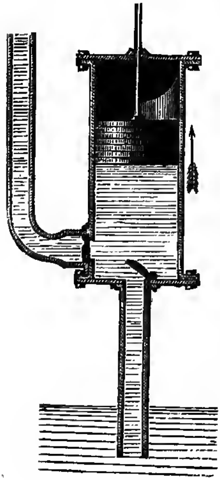


FIG. 114.

296. The Force-Pump.

—In the force-pump, the piston is generally made solid, *i. e.*, without any valve. The upper valve is placed in a discharge pipe which opens from the barrel at or near its bottom. When the piston is raised, water is forced into the barrel by atmospheric pressure. When the piston is forced down, the suction pipe valve is closed, the water being forced through the other valve into the discharge pipe. When next the piston is raised, the discharge pipe valve is closed, preventing the return of the water above it, while atmospheric pressure forces more water from below into the barrel.

297. The Air-Chamber of a Force-Pump.—Water will be thrown from such a pump in spurts, corresponding to the depressions of the piston. *A continuous flow is secured by connecting the discharge pipe with an air-chamber.* This air-chamber is provided with a delivery pipe, *b*, the inner end of which terminates below the surface of the water in the air-chamber. When water is forced into the air-chamber, it covers the mouth of the delivery pipe and compresses the air confined in the chamber. This diminution of volume of the air is attended by a corresponding increase of tension (§ 284), which soon becomes sufficient to force the water through the nozzle of the delivery pipe in a continuous stream.

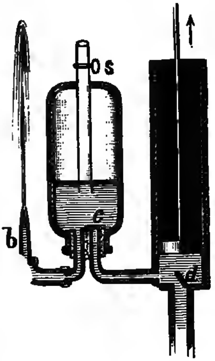


FIG. 115.

298. The Siphon.—The siphon consists of a bent tube, open at both ends, having one arm longer than the other. It is used to transfer liquids from a higher to a lower level, especially in cases where they are to be removed without disturbing any sediment they may contain. It may be first filled with the liquid, and then placed with the shorter arm in the higher vessel, care being had that the liquid does not escape from the tube until the opening

C is lower than *mn*, the surface of the liquid; or it may be first placed in position, and the air removed by suction at the lower end; whereupon, by the pressure of the atmosphere, the fluid will be forced up the shorter arm and fill the tube. In either case a constant stream of the liquid will flow from the upper vessel until the surface line *mn* is brought as low as the opening in the shorter arm, or, if the liquid be received in another vessel, until the level is the same in the two vessels.

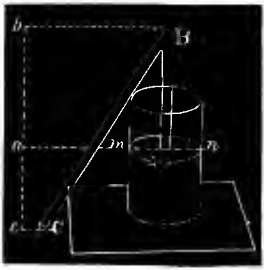


FIG. 116.

299. Explanation of the Siphon.—This action of the siphon may be thus explained: For convenience, suppose that the sectional area of the tube is one inch, that the downward pressure of the water in the arm *AB* is one pound, and that the downward pressure of the water in the arm *BC* is three pounds. The upward pressure in the tube at *A* will equal the atmospheric pressure on each inch of the surface *mn* outside the tube *minus* the downward pressure of one pound, *i. e.*, (15 — 1 =) 14 pounds. On the other side, there is at *C* the upward atmospheric pressure of 15 pounds, from which must be taken the downward pressure of the water in *BC*, leaving a resultant upward pressure of 12 pounds at *C*. The upward pressure at *A* being two ponnds greater than that at *C*, determines the flow of the water *ABC*. The greater the difference between *ba* and *bc*, the greater the velocity of the stream.

300. Limitations.—If the downward pressure at *A* be equal to the atmospheric pressure, the liquid will not flow. Therefore, *if the liquid be water, the height, ab, must be less than 34 feet;* if it be mercury, *ab* must be less than the mercury column of the barometer.

301. Intermittent Springs. — Occasionally a spring is found which flows freely for a time, and then ceases to flow for a time. Fig. 117 represents an underground reservoir, fed with water through fissures in the earth. The channel through which the water escapes from this reservoir forms a siphon. The water escaping at the surface constitutes a spring. When the water in the reservoir reaches the level of the highest point in the channel, the siphon begins to act, and continues to do so until the water level in the reservoir falls to the mouth of the siphon. The spring then ceases to flow until the water has regained the level of the highest point of the siphon-like channel. This action is well illustrated by "Tantalus' Cup," represented in Fig. 118.

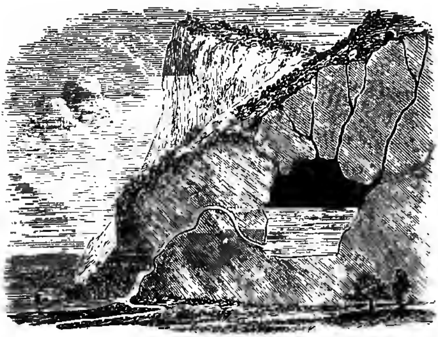


FIG. 117.


FIG. 118.

EXERCISES.

1. How high can water be raised by a *perfect* lifting-pump, when the barometer stands at 30 inches? (See § 253, [2].)

2. If a lifting-pump can just raise water 28 ft., how high can it raise alcohol having a specific gravity of 0.8?

3. Water is to be taken over a ridge 12.5 *m.* higher than the surface of the water. (*a.*) Can it be done with a siphon? Why? (*b.*) With a lifting-pump? Why? (*c.*) With a force-pump? Why?

4. How high will bromine stand in an exhausted tube, when mercury stands 755 *mm.*? (Sp. gr. of bromine = 2.96.)

5. If water rises 34 feet in an exhausted tube, how high will sulphuric acid rise under the same circumstances?

6. The sectional area of the piston of a "weight-lifter" being 15 sq. inches, what weight could the instrument raise?

7. If the capacity of the barrel of an air-pump is $\frac{1}{4}$ that of the receiver, (*a.*) what part of the air will remain in the receiver at the end of the fourth stroke of the piston, and (*b.*) how will its tension compare with that of the external air?

8. How high could a liquid with a sp. gr. of 1.35 be raised by a lifting-pump when the barometer stands 29.5 inches?

9. Over how high a ridge can water be continuously carried in a siphon, the minimum standing of the barometer being 69 *cm.*?

10. What is the greatest pull that may be resisted by Magdeburg hemispheres (*a.*) 4 inches in diameter? (*b.*) 8 *cm.* in diameter? (See Appendix A.)

Recapitulation.—In this section we have considered the Air-pump; the Limits of Exhaustion attainable by the ordinary air-pump; Sprengel's and Bunsen's air-pumps; the Condenser and Transferrer; numerous Experiments pertaining to aëriform pressure and tension; the Lifting-pump; the Force-pump; the Siphon and Intermittent Springs.

REVIEW QUESTIONS AND EXERCISES.

1. Define (*a.*) Physics, (*b.*) Chemistry, (*c.*) Atom, (*d.*) Molecule, (*e.*) Solids, (*f.*) Liquids and (*g.*) Aëriform Bodies.

2. Define (*a.*) Inertia, (*b.*) Impenetrability and (*c.*) Hardness, illustrating each by examples.

3. (*a.*) Define Momentum and (*b.*) Energy. A body weighs 500 lbs., and has a velocity of 60 ft. per second; (*c.*) what is its momentum and (*d.*) what its energy? (*e.*) How would each be affected by doubling the weight? (*f.*) By doubling the velocity?

4. Give (*a.*) the facts and (*b.*) the laws of gravity. A body weighs 1440 lbs. at the surface of the earth; (*c.*) how far above the surface will its weight be 90 lbs.? (*d.*) What will it weigh 2200 miles below the surface?

5. (*a.*) What is a machine? (*b.*) What is a foot-pound? (*c.*) Tell how the advantage gained by a simple mechanical power is found; and (*d.*) show this by an illustration of your own. (*e.*) Explain the cause of friction.

6. (*a.*) What is a simple pendulum? (*b.*) What is an oscillation? (*c.*) How does a change of latitude change the number of vibrations? (*d.*) Why?

7. (*a.*) What is the length of a second's pendulum? (*b.*) What is the length of one vibrating $\frac{1}{3}$ seconds?

8. (*a.*) State the general law of machines, and (*b.*) illustrate it by means of the pulley.

9. (*a.*) What is the centre of gravity? (*b.*) How found?

10. (*a.*) Draw figures illustrating the position of parts in the different kinds of levers; (*b.*) make and solve a simple problem in each.

11. (*a.*) What is the relation which the length of a pendulum bears to its time of oscillation? (*b.*) Give the length of a pendulum beating once in $2\frac{1}{2}$ seconds.

12. (*a.*) Give the second and third laws of motion, and (*b.*) illustrate them.

13. A and B, at opposite ends of a bar 6 ft. long, carry a weight of 600 pounds suspended between them. A's strength being twice as great as B's, how far from A must the weight be suspended?

14. (*a.*) Give the formulas for falling bodies, (*b.*) translating them into common language. (*c.*) Give the same for bodies rolling freely down inclined planes. A body fell from a balloon one mile above the surface of the earth; (*d.*) in what time, and (*e.*) with what velocity would it reach the earth?

15. A ball thrown downward with a velocity of 35 feet per second reaches the earth in $12\frac{1}{2}$ seconds. (*a.*) How far has it moved, and (*b.*) what is its final velocity?

16. (*a.*) A bricklayer's laborer with his hod weighs 170 pounds; he puts into the hod 20 bricks weighing 7 pounds each; he then climbs a ladder to a vertical height of 30 feet. How many units of work does he? (*b.*) If he can do 158,100 units of work in a day, how many bricks will he take up the ladder in a day?

17. Define three accessory properties of matter.

18. How much weight will a cubic meter of any solid lose when weighed (*a.*) in hydrogen? (*b.*) in air? (*c.*) in carbonic acid gas?

19. Can yon devise a plan by which an ordinary mercurial barometer may be used to measure the rarefaction secured by an air-pump?

20. (*a.*) Give the laws of liquid pressure, and (*b.*) find the pressure on one side of a cistern filled with water, 5 feet square and 12 feet high?

21. (*a.*) What is specific gravity? (*b.*) What the standard for liquids and solids? (*c.*) How is the sp. gr. of solids found?

22. Calculate the atmospheric pressure upon a man having a body surface of 16,000 *sq. cm.*

23. What is the upward pull of a balloon of 1,000 *cu. m.*, when filled with gas half as heavy as air, its own weight being 25 *Kg.*?

24. (*a.*) State Archimedes' principle. (*b.*) How may it be experimentally verified? (*c.*) In finding specific gravity, what is *always* the dividend and what is *always* the divisor? (*d.*) A specific gravity bulb weighs 38 *g.* in air, 28 *g.* in water, and 20 *g.* in an acid. Find the sp. gr. of the acid.

25. (*a.*) Describe an overshot water-wheel, and (*b.*) give a drawing.

26. (*a.*) Define the three kinds of equilibrium. (*b.*) Where is the centre of gravity in a ring? (*c.*) Why are lamps, clocks, etc., provided with heavy bases?

27. Find the weight in sulphuric acid (sp. gr. 1.75) of a piece of lead weighing 150 *g.*, and having a sp. gr. of 11.

28. A pendulum 1 meter long makes 40 oscillations in a given time; how long must a pendulum be to make 60 oscillations in the same time and at the same place?

29. (*a.*) Give Mariotte's law. (*b.*) How high could a fluid having a sp. gr. of 1.35 be raised in a common pump when the barometer stands at 29.5 inches?

30. Represent, by drawings in section, the essential parts of (*a.*) an air-pump, (*b.*) a lifting-pump, and (*c.*) a force-pump. (*d.*) Why does the water rise in the suction pipe of a lifting-pump? (*e.*) What is the *immediate* force that throws water in a steady stream from a force-pump?

31. Water flows from an orifice 25 feet below the surface of the water, and 144.72 feet above the level ground. Find the range of the jet.

32. State briefly, by diagram or otherwise, the distinguishing features of solid, liquid and aëriform bodies.

33. The specific gravity of 1 cu. ft. of wood is 0.9. What is the specific gravity of 1 *cu. cm.*?

CHAPTER VI.

ELECTRICITY AND MAGNETISM.

SECTION I.

GENERAL VIEW.

Note.—A desire to secure favorable atmospheric conditions for experiments in frictional electricity has determined the order in which the following branches of physics are taken up. In most places in this country, the school-year begins with September. In such cases, this chapter would probably be reached by January, during which month the atmosphere is generally dry. Under other circumstances, the consideration of these subjects would better be omitted until sound, heat and light have been studied. The experiments in this chapter are numbered consecutively.

302. Simple Apparatus.—Provide two stout sticks of sealing-wax and one or two pieces of flannel folded into pads about 20 centimeters (8 inches) square; two glass rods or stout tubes closed at one end, 30 or 40 centimeters in length and about 2 centimeters in diameter (long "ignition tubes" will answer) and one or two silk pads about 20 centimeters square, the pads being three or four layers thick; a few pith balls about 1 centimeter in diameter (whittle them nearly round and finish by rolling them between the palms of the hands); a silk ribbon about an inch wide and a foot long; a balanced straw about a foot long, represented in Fig. 119. The ends of the straw carry two small discs of paper (bright colors preferable) fastened on by sealing-wax. The cap at the middle of the straw is a short piece of straw fastened by sealing-wax. This is supported upon the point of a sewing-needle, the other end of which is stuck upright into the cork of a small glass vial. From the ceiling or other convenient support, suspend one of the pith balls by a fine silk thread.

FIG. 119.

(*a.*) The efficiency of the silk pad above mentioned may be increased by smearing one side with lard and applying an amalgam made of one weight of tin, two of zinc and six of mercury. The amalgam that may be scraped from bits of a broken looking-glass answers the purpose admirably.

Experiment 1.—Draw the silk ribbon between two layers of the warm flannel pad with considerable friction. Hold it near the wall of the room. *The ribbon will be drawn to the wall and held there for some time.* Place a sheet of paper on a warm board and briskly rub it with india-rubber. Hold it near the wall as you did the ribbon.

Experiment 2.—Briskly rub the sealing-wax with the flannel and bring the wax near the suspended pith ball. The ball will be drawn to the wax. Bring the wax near one end of the balanced straw; it may be made to follow the wax round and round. Bring it near small scraps of paper, shreds of cotton and silk, feathers and gold leaf, bran and sawdust and other light bodies; *they are attracted to the wax.*

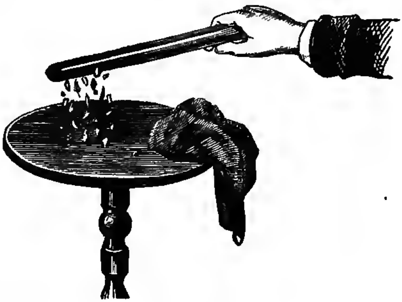


FIG. 120.

Experiment 3.—Repeat all of these experiments with a glass rod that has been rubbed with the silk pad.

Experiment 4.—Make a light paper hoop or an empty egg-shell roll after your rod. (See § 332 *b.*)

Experiment 5.—Place an egg in a wine-glass or an egg-cup. Upon the egg, balance a yard-stick or a common lath. The end of the stick may be made to follow the rubbed rod round and round. Place the blackboard pointer or other stick in a wire loop (Fig. 121) or stiff paper stirrup suspended by a stout silk thread or narrow silk ribbon. It may be made to imitate the actions of the balanced straw or lath.

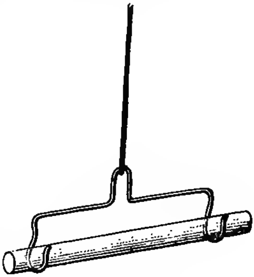


FIG. 121.

Experiment 6.—Suspend the rubbed sealing-wax or glass rod as you did the blackboard pointer in the last experiment. Hold your hand near the end of the rod. *It will turn round and approach your hand.*

Note.—The pupil may be ingenious enough to *invent new experiments* for himself and the class. The ability to invent is often very valuable and may be acquired early in life. Most of the great inventors began making experiments when mere children.

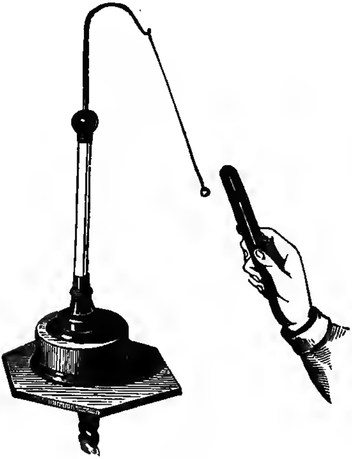


FIG. 122.

303. Electric Attraction.

— *The attractions manifested in the experiments just described were due to electricity that was developed by friction. Such electricity is called frictional or static electricity.*

Experiment 7.—Bring the rubbed sealing-wax or glass rod near the pith ball again. It will attract the ball as before. Allow the ball to touch the rod and notice that, in a moment, the ball is thrown off. If the ball be pursued with the rod, it will be found that *the rod which attracted it a moment ago now repels it.* Evidently, the ball has acquired a new property. (Fig. 123.)

Experiment 8.—Touch the ball with the finger. It seeks the rubbed rod, touches the rod, flies from the rod. Repeat the experiments with the sealing-wax after it has been rubbed with flannel.

Experiment 9.—Rub the glass rod with silk and bring it over the small scraps of paper as before. Notice that, after the attraction, the paper bits do not merely fall down, *they are thrown down.*

304. Electric Repulsion. — *The repulsions manifested in the experiments just described were due to static electricity.* The glass or wax is said to be electrified by friction. The ball, after obtaining its new property of repulsion by coming in contact with the glass or wax, is said to be electrified by conduction. The suspended pith ball is called an *electric pendulum.*

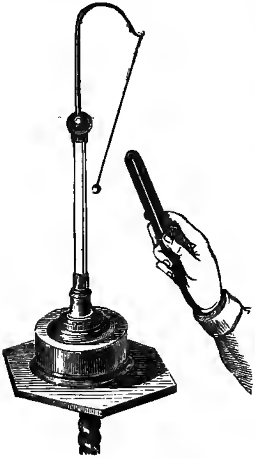


FIG. 123.

Experiment 10.—Prepare a battery solution according to the recipe given in § 392, using only half the quantity of each substance as therein directed. While the solution is cooling, provide a piece of sheet copper and one of sheet zinc, each about 10 centimeters (4 inches) long and 4 centimeters (1½ inches) wide. To one end of each strip, solder (see Appendix B) or otherwise fasten a piece of No. 18 copper wire (See Appendix I) about 15 centimeters (6 inches) long. Place the zinc strip in a common tumbler about three-fourths full of the battery solution. Notice the minute bubbles that break away from the surface of the zinc and rise to the surface of the liquid. These are bubbles of hydrogen, a combustible gas. *The formation of the gas is due to chemical action between the zinc and the liquid.*

Experiment 11.—Take the zinc from the tumbler and, while it is yet wet, rub a few drops of mercury (quicksilver) over its surface until it has a brilliant, silver-like appearance. Replace the zinc, thus amalgamated, in the solution and notice that *no bubbles are given off.*

Experiment 12.—Place the copper strip in the liquid, taking care that it or its wire does not touch the zinc or its wire. *No bubbles appear either on the zinc or the copper.* It may be convenient to place a narrow glass strip between the ends of the metal strips in the tumbler to keep them apart.

Experiment 13.—Bring the upper ends of the strips together, as shown in Fig. 124, or, still better, join the two wires, as shown in Fig. 179, being sure that the wires are clean and bright where they are united. *Notice the formation of bubbles on the surface of the copper, where none previously appeared.*

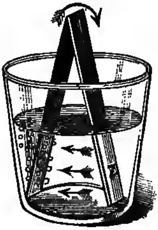


FIG. 124.

305. Suspicion.

—It seems that the connecting wire is an important part of the apparatus as now arranged and we are led to suspect that something unusual is taking place in the wire itself. It is evident that we have a complete "circuit" through the liquid, the metal strip and the wire.

Experiment 14.—Untwist the wires or, in other words, "break the circuit." Connect the copper wires with a short piece of *very fine* iron wire. The connections should be made so that the circuit shall include about 2 centimeters ($\frac{3}{4}$ inch) of iron wire. *The iron will become hot* enough to burn the fingers or to ignite a small quantity of gun cotton twisted around it.

FIG. 125.

Experiment 15.—If one of the copper wires be twisted around one end of a small file and the free end of the other wire be drawn along its rough surface, *a series of minute sparks will be produced* as the circuit is rapidly made and broken.

Experiment 16.—Place the cell so that the joined wires shall run north and south, passing directly over the needle of a small compass (Experiment 98) and near to it. *The needle will instantly turn* as though it were trying to place itself at right angles to the wire. Break the circuit and the needle will swing back to its north and south position.

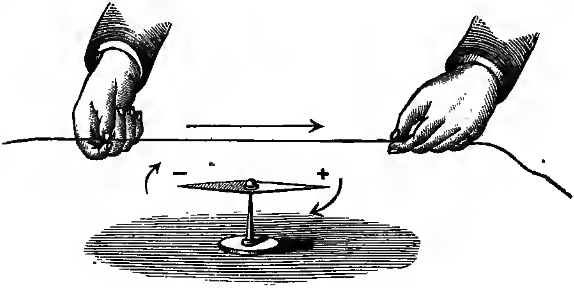


FIG. 126.

306. Certainty.—We now feel sure that something unusual is taking place in the wire of our complete circuit, for we have seen the wire become hot, explode gun-cotton, yield sparks and exert a very mysterious influence upon the magnetic needle. As a matter of fact, we now have a current of electricity flowing through a voltaic cell and wire. *Electricity thus produced by chemical action is called voltaic or galvanic electricity. It is one form of current electricity.*

Experiment 17.—Wrap a piece of writing paper around a large iron nail, leaving the ends of the nail bare. Wind fifteen or twenty turns of stout copper wire around this paper wrapper, taking care that the coils of the wire spiral do not touch each other or the iron. It is well to use cotton covered or "insulated" wire. Connect the two ends of the wire spiral with the two wires of the voltaic cell or, in other words, put the spiral into the circuit. Dip the end of the nail into iron filings. *Some of the filings will cling to the nail in a remarkable manner.* Upon breaking the circuit, the nail instantly loses its newly acquired power and drops the iron filings.

If the experiment does not work satisfactorily, look carefully to all the connections of the circuit, see that the ends of the wires are clean and bright and that they are twisted together firmly. It may be necessary to wash the plates, rub more mercury on the zinc and provide a fresh battery solution.

307. Temporary Magnets.—The nail has the power of attracting iron filings *while the electric current is flowing through the surrounding wire coil. You have made an electro-magnet. Its power of attracting iron is called magnetism.* Satisfy yourself, by trial, that the nail loses its magnetism as soon as the circuit is broken or the current ceases to flow around it. Remember that your electro-magnet is a *temporary magnet.*

Experiment 18.—While the nail is magnetized, draw a sewing-needle four or five times from eye to point across one end of the electro-magnet. Dip the needle into iron filings; *some of them will cling to each end of it.*

308. Permanent Magnets. — When steel is treated as in the last experiment, it becomes permanently magnetized.

Experiment 19.—Cut a thin slice from the end of a vial cork and, with its aid, float your magnetized needle upon the surface of a bowl or saucer of water. *The needle comes to rest in a north and south position.* Turn it from its chosen position and notice that, after each displacement, it resumes the same position and that *the same end of the needle always points to the north.*

309. A Simple Compass.—*A small magnetized steel bar freely suspended, is called a com-*

pass. The one that you have made may be less convenient than is the compass of the mariner or the surveyor, but it is as reliable.

310. Artificial Magnets.—The electro-magnet and the permanent magnet that you make are, of course, *artificial magnets.* There is a *natural magnet* known as lodestone.

311. Other Forms of Current Electricity.—Electric currents may be generated by the action of other currents of electricity or by the action of magnets. Electricity thus developed is called *induced electricity.* A current of *thermo-electricity* may be generated by heating the junction of two metals that form part or all of a circuit.

312. The Different Forms of Electricity are Identical.—So far as experiment can show, one form of electricity may have a particular property in greater degree than some other form, but all are identical, each having all the properties of any of the others.

Recapitulation.—To be amplified by the pupil for review.

ELECTRICITY.

- **STATIC.** Generally produced by FRICTION and manifesting............ ..
  - ATTRACTION.
  - REPULSION.
- *All Forms of Electricity are identical in Nature.*
- **CURRENT.** Generally produced by
  - CHEMICAL ACTION.
    - LIQUID.
    - PLATES.
    - WIRE.
  - INDUCTION.
  - HEAT.
  - MAGNETS.
    - TEMPORARY.
    - PERMANENT.
    - COMPASS NEEDLES.

SECTION II.

FRICTIONAL ELECTRICITY OR ELECTRIC CHARGES.

313. The Nature of Electricity.—But little is known concerning the real nature of electricity. It is easier to tell what electricity can do than to tell what it is. The majority of modern physicists consider that *electricity is a form of energy producing peculiar phenomena; that it may be converted into other forms of energy and that all other forms of energy may be converted into it.* It is believed that electricity is a form of molecular motion, but this belief still rests upon analogy rather than demonstration. Several theories have been advanced to account for electrical phenomena, but none of them is satisfactory.

314. Electric Manifestations. — *Electricity may reveal itself as a charge residing on the surface of a body or as a current flowing through its substance.* By means of friction, the glass rod or the sealing-wax (§§ 303, 304) acquired an electrical charge and, consequently, the power of attracting and repelling light bodies; by means of chemical action, the voltaic cell (§ 306) generated electricity that manifested itself as a current. *In this section, we shall consider electricity that appears as a charge, i.e., static electricity.*

(*a*.) The electrified body is said to be charged. When the electricity is removed, the body is said to be discharged. Good conductors (§ 324) are instantly discharged when touched by the hand, or by any good conductor connected with the earth. A poor conductor may be readily discharged by passing it rapidly through a flame, as of a lamp or candle.

Experiment 20.—Prepare two electric pendulums. Bring the electrified glass rod near the pith ball of one; after contact, the ball will be repelled by the glass. Bring the electrified sealing-wax near the second pith ball; after contact, it will be repelled by the wax. Satisfy yourself that the electrified glass will repel the first; that the electrified sealing-wax will repel the second. Let the glass rod and the sealing-wax change hands. The first ball was repelled by the glass; *it will be attracted by the sealing-wax.* The second ball was repelled by the sealing-wax; *it will be attracted by the glass.*

Experiment 21.—Suspend two pith balls as shown in Fig. 127, and touch them with a rubbed glass rod. Instead of continuing to hang side by side, they repel each other and fly apart. If the electrified glass rod be held near them, they separate still further. If the electrified sealing-wax, instead of the glass, be held near them, they will fall nearer together. If the rubbed glass rod be suspended as shown in Fig. 121, it will be repelled by another rubbed glass rod, but attracted by rubbed sealing-wax.

FIG. 127.

315. Two Kinds of Electricity.—*The electricity developed on glass is different in kind from that developed on sealing-wax.* They exhibited opposite forces to a third electrified body, each attracting what the other repels.

Experiment 22.—Hold the silk pad in a piece of sheet-rubber and, with it, rub the glass rod. Suspend the glass rod and bring the silk pad near it. The electrified pad will attract the glass, but will repel a suspended stick of sealing-wax that has been rubbed with flannel.

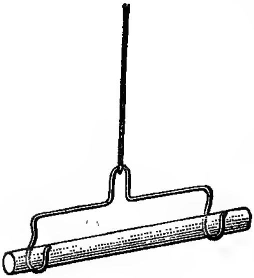


FIG. 128.

316. Electric Separation.—*All electrified bodies act like either the glass or the sealing-wax.* When the glass rod was positively electrified, an equal amount of negative electricity was simultaneously developed in the silk with which it was rubbed. When the sealing-wax was negatively electrified, an equal amount of positive electricity was developed at the same time in the flannel. It is as though the two electricities were united in these several substances in their ordinary condition and were torn asunder by the friction, thus producing actual "electric separation."

(*a*.) If it be desired to show that the rubber has been electrified, care must be taken not to handle it too much. For example, if sealing-wax is to be rubbed with a piece of fur, do not take the fur in the hand, but fasten it to the end of a glass rod as a handle.

(*b*.) That the electricities thus simultaneously developed are opposite in kind and equal in amount may be shown by imparting the electricity of the rubber and the electricity of the thing rubbed to a third body, which will then show no electrification at all. The equal and opposite electricities exactly neutralize each other.

317. The Two Electricities Named.—As the two kinds of electricity are opposite in character, they have received names that indicate opposition. *The electricity developed on glass by rubbing it with silk* *is called positive or +. The electricity developed on sealing-wax by rubbing it with flannel is called negative or —.* The terms *vitreous* and *resinous* respectively were formerly used.

318. Electric Series.—In the following list, the substances are named in such an order that, if any two be rubbed together, the one that stands earlier in the series becomes positively electrified and the one that is mentioned later becomes negatively electrified: *fur, wool, resin, glass, silk, metals, sulphur, india-rubber, gutta percha, collodion.*

319. The Laws of Electrostatics.—The most important electrostatic laws may be stated thus:

(1.) *Electric charges of like signs repel each other; electric charges of opposite signs attract each other.*

(2.) *The force exerted between two electric charges is directly proportional to their product and inversely proportional to the square of the distance between them.* This is known as Coulomb's law. The two charges are supposed to be collected at two points, or on two very small spheres. $f = \frac{Q \times q}{d^2}$.

(*a.*) Suppose that a and b are two small balls, each charged with a quantity of electricity, that we shall call unity. Then the product of the charges will be $1 \times 1 = 1$. Next, suppose that A and B are two similar balls, that A is charged with twice as much electricity as a and that, similarly, B has a charge represented by 3. The product of the charges of A and B will be $2 \times 3 = 6$. In other words, at equal distances, the repulsion between A and B will be six times as great as the repulsion between a and b.

(*b.*) Suppose that two electric charges or two small electrified bodies one inch apart repel each other with a certain force; at a distance of two inches, they will repel each other with a force one quarter as great; at a distance of ten inches, they will repel each other with only one *per cent.* of the original force at the distance of one inch.

320. Electrical Units.—There are two systems of electrical units derived from the fundamental "C.G.S." units, one set being based upon the attraction or repulsion exerted between two quantities of electricity and the other upon the force exerted between two magnet poles. The former are termed *electrostatic* units; the latter, *electromagnetic* units.

321. Electrostatic Unit of Quantity.—*One unit of electricity is that quantity which, when placed at a distance of one centimeter from a similar and equal quantity, repels it with a force of one dyne.* It is a C.G.S. unit (§ 69) and has no special name.

(*a.*) Two small spheres, charged respectively with 6 units and 8 units of + electricity, are placed 4 *cm.* apart; find what force they exert on one another.

By the formula, $f = \frac{Q \times q}{d^2}$, we find $f = \frac{6 \times 8}{4^2} = \frac{48}{16} = 3$.

Ans. 3 dynes.

The force in the above example would clearly be a force of repulsion. Had one of these charges been negative, the product, $Q \times q$, would have had a − value (algebraic) and the answer would have been *minus* 3 dynes. The algebraic − sign, therefore, prefixed to a force, indicates that it is a force of *attraction*, while the + sign signifies a force of *repulsion.*

322. The Test for Either Kind of Electricity.—When the pith ball was attracted by the rubbed glass it became, during the time of contact, charged with the + electricity of the glass; hence it was repelled. When it was attracted by the rubbed sealing-wax it became, during the time of contact, charged with the − electricity of the wax; then it was repelled. But either the wax or the glass attracted the uncharged pith ball. We must, therefore, remember that *attraction affords no safe test for the kind of electricity, while repulsion does.* If glass rubbed with silk repels a body, that body is charged with + electricity. If sealing-wax rubbed with flannel repels a body, that body is charged with — electricity.

323. Electroscopes.—*An instrument used to detect the presence of electricity, or to determine its kind, is called an electroscope.* The electric pendulum (§ 304) is a common form of the electroscope. Two strips of the thinnest tissue paper hanging side by side constitute a simple electroscope. It is well to prepare the paper beforehand by soaking in a strong solution of salt in water and drying. The balanced straw (Fig. 119) or, better yet, two gilded pith balls connected by a light needle of glass or sealing-wax balanced horizontally on a vertical pivot, or a goose-quill balanced on the point of a sewing-needle, makes a convenient electroscope.

FIG. 129.

The gold leaf electroscope is represented in Fig. 129. A metallic rod, which passes through the cork of a glass vessel, terminates below in two narrow strips of gold leaf and above in a metallic knob or plate. The object of the vessel is to protect the leaves from disturbance by air currents. The upper part of the glass is often coated with a solution of sealing-wax or shellac in alcohol, to lessen the deposition of moisture from the atmosphere. This instrument may be made by the pupil and, when well made, is very delicate.

(*a.*) The electric pendulum is used as an electroscope as follows: If an uncharged pith ball be attracted by a body brought near it, the body is electrified. To determine the sign of the electricity of the body thus shown to be electrified, the pith ball is allowed to touch it and be repelled. If the ball then be repelled by a glass rod rubbed with silk (or by any other body known to be positively charged), the pith ball and the body in question manifest + electricity. If the pith ball, after repulsion by the body whose electricity is under examination, be repelled by sealing-wax rubbed with flannel (or by any other body known to be negatively charged), the pith ball and the body in question manifest — electricity. Remember that the repulsion and not the attraction constitutes the test.

(*b.*) One way of testing with the gold leaf electroscope is to bring the electrified body *near* the knob; the leaves will diverge. Touch the knob with the finger; the leaves will fall together. Remove first the finger and then the electrified body; the leaves will diverge again. If now the divergence of the leaves be increased by bringing a positively charged body near the knob, the original charge was —; if the divergence be thus diminished, the original charge was +.

(*c.*) The knob and rod of the gold leaf electroscope may be made by soldering a wire to a smooth metal button. The vessel may be any clear glass bottle with a wide mouth. Thrust the wire downward through the cork of the bottle and bend the wire at right angles, so that when the cork is in place the horizontal part of the wire shall be about $\frac{3}{4}$ inch long and come just below the shoulder of the bottle. Cut a strip of gold or Dutch leaf, 4 inches long and $\frac{1}{2}$ inch wide and paste it at its middle line to the horizontal part of the wire, so that the two halves of the strip shall hang downward facing each other. See that the cork is perfectly dry; heat the bottle until it is perfectly dry; insert the cork firmly in its place, and pour melted sealing-wax over the cork and around the mouth of the bottle so that no moisture can get into *your electroscope.* If you cannot get the gold or Dutch leaf (try at some good-natured dentist's or sign painter's), use two discs of gilt paper as large as the mouth of your bottle will admit and tie them to the wire by very short cotton or linen threads.

Experiment 23.—From a horizontal glass rod or tightly-stretched silk cord, suspend a fine copper wire, a linen thread and two silk threads, each at least a meter long. To the lower end of each, attach a metal weight of any kind. Place the weight supported by the wire upon the plate of the gold leaf electroscope. Bring the electrified glass rod near the upper end of the wire; the gold leaves *instantly* diverge. Repeat the experiment with the linen thread; *in a little while* the leaves diverge. Repeat the experiment with the dry silk thread; the leaves do not diverge *at all.* Rub the rod upon the upper end of the silk thread; no divergence *yet appears.* Wet the second silk cord thoroughly and, with it, repeat the experiment; the leaves then diverge *instantly.*

Experiment 24.—Support a yard stick or common lath upon a glass tumbler. Bring the glass rod, electrified by rubbing it with silk, to one end of the stick and hold some small pieces of gold leaf or paper under the other end of the stick. The gold leaf or paper will be attracted and repelled by the stick as it previously was by the glass itself. *The electricity passed along the stick from end to end.*

324. Conductors.—Such experiments clearly show that *some substances transmit electricity readily and that others do not. Those that offer little resistance to the passage of electricity are called conductors; those that offer great resistance are called non-conductors or insulators.* A conductor supported by a non-conductor is said to be insulated.

(*a.*) In the following table, the substances named are arranged in the order of their conductivity:

Conductors.
1. Metals.
2. Charcoal.
3. Graphite.
4. Acids.
5. Salt water.
6. Fresh water.
7. Vegetables.
8. Animals.
9. Linen.
10. Cotton.
11. Dry wood.
12. Paper.
13. Silk.
14. India rubber.
15. Porcelain.
16. Glass.
17. Sealing-wax.
18. Vulcanite.

Insulators.

(*b.*) The fact that a conductor in the air may be insulated, shows that air is a non-conductor. Dry air is a very good insulator (at least 10^{26} times as good as copper), but moist air is a fairly good conductor for electricity of high potential. *All experiments in frictional electricity should, therefore, be performed in clear, cold weather* when the atmosphere is dry, for a moist atmosphere renders insulation for a considerable length of time impossible.

(*c.*) A simple way of determining experimentally whether a body is a good conductor or not is, to hold it in the hand and touch the knob of a charged gold leaf electroscope with it. If the substance be a good conductor, the electroscope will be quickly discharged.

Experiment 25.—Suspend a copper globe or other metal body by a silk thread and strike it two or three times with a cat's skin or fox's brush. Bring the gold leaf electroscope near the globe. The leaves will diverge.

325. Electrics.—*Any substance, when insulated, may be sensibly electrified; but when an uninsulated conductor is rubbed, the electricity escapes as fast as it is developed.* The old division of bodies into electrics and non-electrics, or bodies that can be electrified and those that cannot be electrified, is nothing more than a division into conductors and non-conductors.

326. Tension.—Electricity exists under widely different conditions with respect to its ability to force its way through a poor conductor or to leap across a gap. The electricity developed in a voltaic cell will not pass through even a very thin piece of dry wood; the electricity developed by rubbing the glass rod will pass through several feet of dry wood. It would require a battery of many cells to force a current across an air-filled gap of $\frac{1}{1000}$ of an inch. It is not difficult to force frictional electricity across a gap of several inches, while we all know that, in the case of lightning, electricity leaps across a gap of many hundred feet. In the one case, the electricity is said to be of low potential; in the other case, it is said to be of high potential. The terms "low tension" and "high tension" are often used in the same sense.

327. Potential.—The term, electrical potential (or simply potential), has reference to the electrical condition of a body, or to its degree of electrification. If the potential of *A* be higher than that of *B* and the two bodies be connected by a good conductor, *an electric current will flow from A to B until the potentials are alike.* Difference of potential is somewhat analogous to difference of liquid level and gives rise to electromotive force.

(*a.*) The electric condition of the earth is sometimes taken as the zero of potential. The electric condition of other bodies is then described as being a certain number of units above or below zero; *i.e.*, as being + or —. In determining the flow of liquids, it is not necessary to know the height of either reservoir above the earth's centre or above the sea level, but only the head *or difference of liquid level.* Similarly, *the difference of potential* is what determines the direction and strength of an electric current flowing through a given conductor.

328. Difference of Potential.—*The difference of potential between two points represents the work that must be done in carrying a + unit of electricity* (§ 321) *from one point to the other.* The work done will be the same, whatever the path along which the unit is moved from one point to the other. Similarly, the work done in lifting a weight from one point to another at a higher level will be the same whatever the path along which the weight is lifted.

329. Electrostatic Unit of Difference of Potential.—*The unit of difference of potential is that which exists between two points, when it requires the expenditure of one erg to bring a unit of + electricity from one point to another against* *the electric force.* Let A be a small sphere positively electrified and P and Q, two points at different distances from A. If Q is just so far from P that it requires one erg of work to push a unit of + electricity from Q to P, there will be unit difference of potential between P and Q. This unit has no special name.

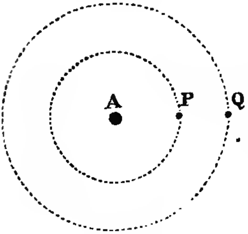


FIG. 130.

(*a.*) Let P and Q be in the outer surfaces of concentric, spherical, shells at the centre of which is A. To move the + unit from one point in either of these surfaces to any other point in the same surface requires no further overcoming of electric forces and, therefore, no expenditure of work. Such a surface is called an *equipotential surface.*

330. Electric Capacity.—Bodies vary in respect to their capacity for holding or accumulating electricity. *The electrostatic unit of capacity is the capacity of a conductor that requires a charge of one unit of electricity to raise its potential from zero to unity.* It has no special name. A sphere of one centimeter radius has unit capacity. The capacities of spheres are proportional to their radii. (See § 359.)

(*a.*) A small conductor (*e.g.*, a sphere the size of a pea) will require less than one unit to raise its potential from 0 to 1; it is of small capacity. A sphere five meters in diameter will require many units to raise its potential from 0 to 1; it is of great capacity. In other words, the electrostatic capacity of a conductor or condenser is measured by the quantity of electricity which must be imparted to it in order to raise its potential from 0 to 1.

331. Charging by Contact.—If an insulated, unelectrified conductor be brought into contact with a similar conductor that is electrified, or near enough to it for the easy passage of an electric spark, electricity will pass from the latter to the former until the two conductors are equally charged with the same kind of electricity, *i.e.*, until they are of the same potential. *The former is said to be charged by conduction.*

332. Electrostatic Induction.—From several of the preceding experiments, we see that actual contact with an electrified body is not necessary for the manifestation of electric action in an unelectrified body. When an electrified body, *C*, is brought near an insulated, unelectrified conductor, *B*, provided with electric pendulums, as shown in Fig. 131, the latter shows electric action. The electricity of *C* repels one kind of electricity in *B* and attracts the other, thus separating them. The second body, *B*, is then said to be *polarized.*

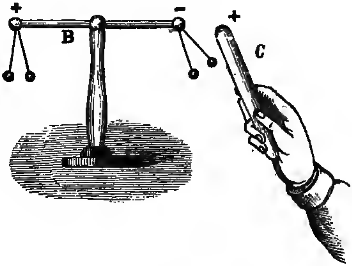


Fig. 131.

The two kinds of electricity in *B*, each of which a moment ago rendered the other powerless, are still there, but they have been separated and each clothed with its proper power. This effect is due to the action of the electrified body, *C*, which is said to produce electric separation *by induction.* This action will take place across a considerable distance, even if a large sheet of glass be held between *B* and *C*. When *C* is removed, the separated electricities of *B* again mingle and neutralize each other.

(*a.*) Conductors for the purposes of this and similar experiments may be made of wood, covered with tin-foil, gold leaf or Dutch leaf. They may be insulated by fastening them on top of long-necked bottles or sticks of sealing-wax, or by suspending them by silk threads.

(*b.*) Prick a pin-hole in each end of a hen's egg and blow out the contents of the shell. Paste tin-foil or Dutch leaf smoothly over the whole surface of the egg. Fasten one end of a white silk thread to the egg with a drop of melted sealing-wax, so that the egg may hang suspended with its greater diameter horizontal. Three or four such insulated conductors will be found convenient. Sometimes, it is better for each egg to have two thread supports. Place a loop or ring at the free end of each thread. When the loops are placed on a horizontal rod (*e.g.*, a piece of glass tubing), the greater diameters of the suspended eggs should lie in the same straight line. An elongated conductor like *AB* of Fig. 133 may be made by hanging two or three egg conductors, so that they are in contact, as shown in Fig. 132.

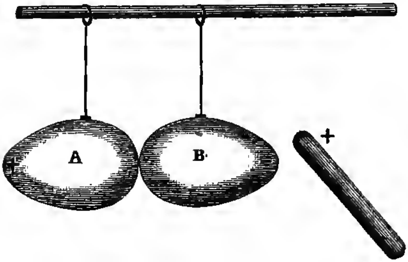


FIG. 132.

Experiment 26.—While the charged glass rod is held near the egg conductors, shown in Fig. 132, bring a pith ball electroscope near. The attraction will be evident at the free ends of the two eggs, but very little, if any, will be found at or near the point where the eggs are in contact.

333. A Neutral Line.—If an insulated conductor, bearing a number of pith·ball (or paper) electroscopes, be brought near an electrified body, *C*, (Fig. 133), but not near enough for a spark to pass between them, the pith balls near the ends of the conductor will diverge, showing the presence of separated or uncombined electricity. The pith balls at the middle of the polarized conductor will not diverge, marking thus a neutral line. If *C* has a positive charge, the charge at *A* will be negative and that at *B* will be positive, as may be shown by charging an electric pendulum and testing at *A* and *B*.

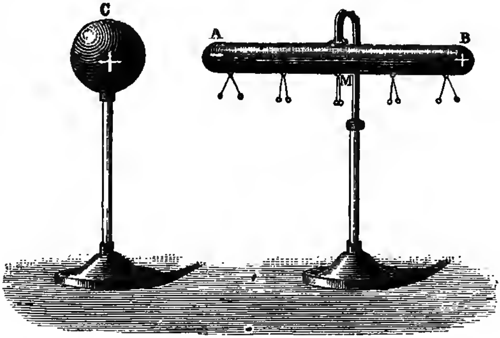


FIG. 133.

If *C* be removed or "discharged" by touching it with the hand, all traces of electrical separation in *A B* will disappear. The charged pith ball will be attracted at every point of *A B*.

Experiment 27.—While the charged glass rod is held near the egg conductors shown in Fig. 132, slide the loop, carrying *A* about 4 inches (10 *cm.*) to the left and *then* hold the rod between the two eggs. *The rod will repel one egg and attract the other.*

334. Charging a Body by Induction.—If the polarized conductor be touched with the hand, or otherwise placed in electric communication with the earth, the electricity repelled by *C* (Fig. 133) will escape, and the pith balls at *B* will fall together. The electricity at the other end will be held by the mutual attraction between it and its opposite kind at *C*. The line of communication with the ground being broken and the conductor being removed from the vicinity of *C*, it will be found charged with electricity opposite in kind to that of *C*.

A body may be thus charged by induction with no loss to the inducing body. If the conductor, *A B*, be made in two parts and the parts separated, while under the inductive action of the electrified body, *C*, the two electricities can no longer return to neutralize each other, but must remain, each on its own portion of the conductor. The two parts will thus be oppositely charged.

335. Successive Induction.—If a series of insulated conductors, like the egg shells of Fig. 132, be placed in line as shown in Fig. 134, and a positively electrified body be brought near, each conductor will be polarized. The first will be polarized by the influence of the + of *C*; the second by the influence of the + of *M*, and so on.

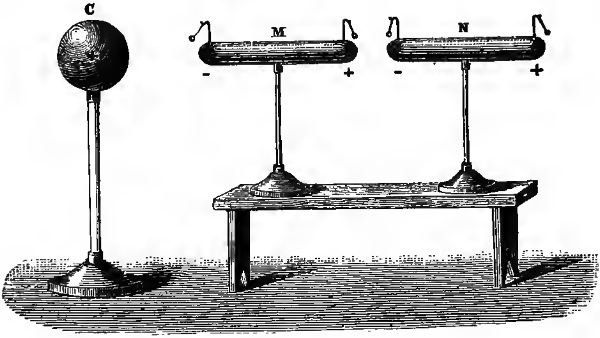


FIG. 134.

(*a.*) Either kind of electricity may be carried from *M* or *N* by a small insulated body, called a proof-plane (Fig. 139), to the electroscope, there tested and found to be as represented in the figure. If the conductors, *M* and *N*, be now placed in actual contact, the + of both will be repelled by *C* to the furthest extremity of *N* and the — of both will be attracted to the opposite end of *M*, near to *C*.

(*b*.) It is very plain that any body may be looked upon as a collection of many parallel series of such conductors, each molecule representing a conductor. Thus, each molecule may be polarized, + at one end and − at the other. If the body in question be a good conductor of electricity, *this polarization of the molecules is only for an instant.* The two electricities pass from molecule to molecule and accumulate at opposite ends of the body. The body is then polarized, but not the molecules of the body. On the other hand, good insulators resist this tendency to transmit the electricities from molecule to molecule and are able to maintain a high degree of molecular polarization for a great length of time. In brief, the molecules of conductors easily discharge their electricities into each other; those of non-conductors do not.

336. Polarization Precedes Attraction.—

When an electrified glass rod is brought near an electric pendulum, the pith ball is polarized as shown in the figure. As the − electricity of the ball is nearer the + of the glass than is the + of the ball, the attraction is greater than the repulsion. If the pith ball be suspended, not by a silk thread but by some good conductor, the attraction will be more marked, for the + of the ball will escape to the earth through the support and, thus, the repelling component will be removed.

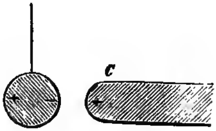


FIG. 135.

Note.—Polarization and electrification by induction explain a great many electrical phenomena.

337. Provisional Theory of Electricity.—

While the real nature of electricity remains unknown, the following theory will be found convenient for classifying results already attained and suggesting directions for further inquiry. But we must not let it influence our judgment as to what is the true and full explanation of electrical phenomena, which explanation may be found hereafter:

(1.) *We may assume that a neutral or unelectrified body contains equal and equally distributed quantities of positive and of negative electricity.*

(2.) *We may assume these electricities to be unlimited in amount.*

(3.) *We shall then conceive that a positively electrified body has an excess of + electricity and that a negatively electrified body has an excess of — electricity.*

(4.) *In this light, we shall see that communicating + electricity to a body is equivalent to removing an equal amount of — electricity from it, and conversely.*

338. The Electrophorus.—This simple instrument consists generally of a shallow tinned pan filled with resin, on which rests a movable metallic cover with a glass or other insulating handle. The resinous plate may be replaced by a piece of vulcanized india-rubber. The metal surface and the resinous surface touch at only a few points; they are practically separated by a thin layer of insulating air.

(*a.*) The resinous plate may be prepared by melting together equal quantities of resin and Venice turpentine and then adding a like quantity of shellac. The substances should be heated gradually and stirred together so as to prevent the forming of bubbles. Be careful that the mixture does not take fire in course of preparation. The Venice turpentine is desirable, but not necessary. For a handle, a stout wire may be soldered to the centre of the disc and covered with rubber tubing, or a piece of sealing-wax, of convenient size, may be fastened to the disc for the purpose. A still better plan is to make the cover of wood, a little less in diameter than the resinous plate. Its edges should be carefully rounded off. For a handle, a glass rod or tube may be tightly thrust or cemented into a hole in the middle of the cover. Place tinfoil all over the cover and smooth down all rough edges of the foil with the finger-nail or paper-folder. The wire support for a pith ball or paper electroscope may be thrust into the wood of the cover, care being taken that it touches the tinfoil.

FIG. 136.

(*b.*) For an electroscope for the electrophorus, provide a bit of wire about 8 *cm.* long and bend it at right angles about 1 *cm.* from each end. Solder one of the bent arms of the wire (see Appendix B) to the upper side of the metal cover, near its edge, in such a way that the central part of the wire shall be vertical. Cut a strip of gold leaf (or Dutch metal) about 8 *cm.* long and 8 *mm.* wide. Moisten the *sides* of the free horizontal wire-arm with a little mucilage, place the middle of the gold-leaf strip over the top of the arm and bring the ends of the leaf down to a vertical position, touching each other. The mucilage will hold the leaf to the wire. When the wire support and gold leaves are electrified, the latter will diverge. When the apparatus is not in use, this electroscope may be protected by inverting a tumbler or beaker glass over it.

(*c.*) The plate is rubbed or struck with flannel or catskin and thus negatively electrified. The cover is then placed upon the resin and thus polarized by induction. If the cover be provided with a gold-leaf electroscope, the free negative electricity of the cover will cause the leaves to diverge; the positive electricity of the cover will be "bound" on the under side of the cover by the attraction of the negative electricity of the resin. Remove the cover and the separated electricities reunite, as is shown by the falling together of the lately divergent gold leaves. Place the cover again upon the resin. Polarization is manifested by the divergence of the leaves. Touch the cover with the finger as shown in the figure; the − electricity escapes and the leaves fall. The cover is now charged positively, but its electricity is all "bound" at its under surface and cannot cause the leaves to separate. Remove the cover by its insulating handle and the electricity, lately "bound" but now "free," diffuses itself and the leaves are divergent with + electricity. The charged cover will give a spark to the knuckle or other unelectrified body presented to it. (Fig. 137.)

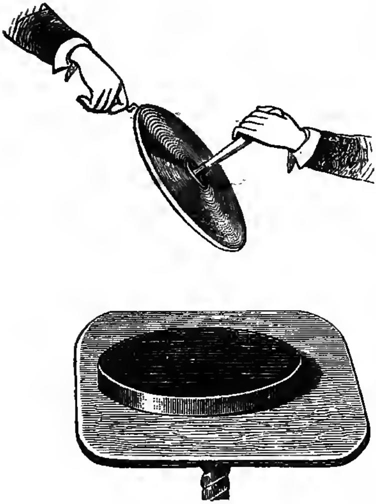


FIG. 137.

339. The Electrophorus Charged by Induction.—The cover may be thus charged and discharged an indefinite number of times, in favorable weather, without a second electrifying of the resinous plate. This could not happen if the electricity of the cover were drawn from the plate. Moreover, if the charge of the cover were drawn from the plate, it would be —, and not +. There is no escape from the conclusion that the *cover is charged by induction and not by conduction.*

(*a.*) If the resin were a good conductor like the metal cover, its molecules would all receive + electricity from the cover and give — electricity to it. But as the resin is a poor conductor, only the very few molecules that come in actual contact with the cover at each charging have their electrical equilibrium restored. The + of the cover cannot readily pass through them to their electrified neighbors. Hence, it requires a great many placings of the cover upon the plate to discharge the resin by reconveying to it the + electricity removed at its electrification. When the cover is charged, it gives up part of its — electricity; when it is discharged, it receives this — electricity back again from the body that discharges it. As this giving and taking is neither to nor from the resin, it may be continued almost indefinitely. A Leyden jar (§ 353) may be charged with an electrophorus.

340. Whence this Energy?—At every discharge of the electrophorus, it gives a definite amount of electricity, capable of doing a definite amount of work. As this is obtained not by the expenditure of any part of the original charge, we are led to seek for *the source of this apparently unlimited supply of energy.*

"As a matter of fact, it is a little harder work to lift the cover when it is charged with the + electricity than if it were not charged, for, when charged, there is the force of electric attraction to be overcome as well as the force of gravity. Slightly harder work is done at the expense of the *muscular energies* of the operator and this is

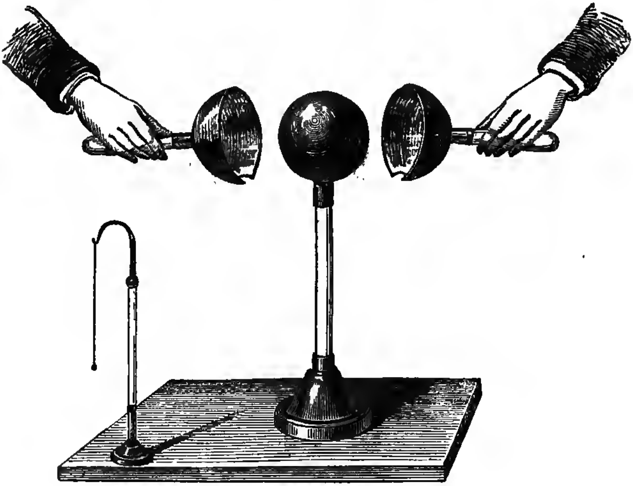


FIG. 138.

the real origin of the energy stored up in the separate charges."

Experiment 28.—Insulate a metal globe and provide it with two closely fitting hemispherical shells that have insulating handles. Electrify the globe; bring it near the electroscope to be sure that it is electrified. Place the hemispheres upon the globe. Remove them quickly, being careful that their edges do not touch the sphere after the first separation. (Fig. 138.) Bring first one shell and then the other near the electroscope; they are electrified. Bring the globe itself near the electroscope. *It is no longer electrified.* Delicate manipulation is needed to make the experiment successful. You will fail, perhaps, more times than you succeed. But when the experiment is successful, it is instructive. The apparatus is called Biot's hemispheres.

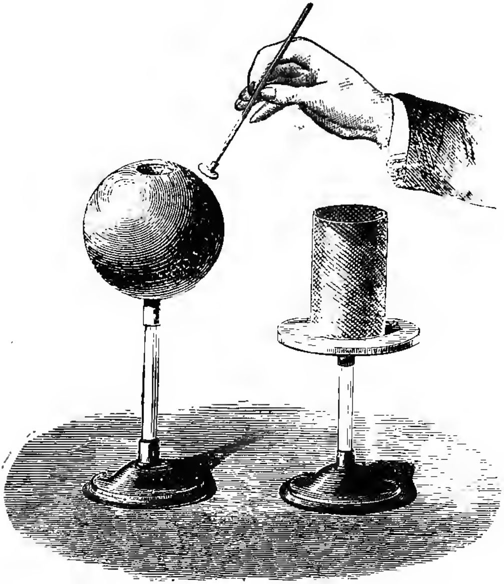


FIG. 139.

Experiment 29.—By means of a few sparks from the electrophorus, charge an insulated hollow sphere, having an orifice in the top. Bring a proof-plane (made by fastening a disc of gilt paper to a long, thin insulating handle) into contact with the outer surface of the sphere. The proof-plane is charged by the sphere, as may be shown by bringing it near an electroscope. Discharge the proof-plane and bring it into contact with the inner surface of the sphere. Remove it carefully without allowing it to touch the sides of the orifice. Bring it to the electroscope. *It is not charged.* (Fig. 139.) An empty tin fruit can supported on a clean, dry, glass tumbler will answer for the experiment.

Experiment 30.—Make a conical bag of linen, supported, as shown in Fig. 140, by an insulated metal hoop five or six inches in diameter. Charge the bag with the electrophorus. A long silk thread extending each way from the apex of the cone will enable you to turn the bag inside out without discharging it. Test the inside and outside of the bag, using the proof-plane described above. Turn the bag and repeat the test. Whichever surface of the linen is external, *no electricity can be found upon the inside of the bag.* Nothing can be more conclusive than this.

FIG. 140.

Experiment 31.—Vary the experiment by the use of a hat suspended by silk threads. Notice that the greatest charge can be obtained from the edges; less from the curved or flat surface; none from the inside.

341. A Charge Resides on the Surface.—

Many experiments have been made showing that *when a conductor is electrified, the electricity passes to the surface and escapes if the body be not insulated.* A bomb-shell and a cannon ball of equal diameter will receive equal quantities of electricity from the same source. The hollow conductors commonly used in experiments with static electricity are as serviceable as if they were solid. A wooden prime conductor coated with gold-leaf is as efficient as if it were made of solid gold. Experiment is unable to find any difference in this respect between a solid sphere of metal and the thinnest soap-bubble of the same diameter.

(*a.*) This does not apply to an electric current. A hollow wire will not conduct electricity as well as a solid wire of the same diameter. Electricity may be *drawn* to the inside of a hollow conductor by placing there an electrified, insulated body.

(*b.*) The linen bag of Experiment 30 was devised by Michael Faraday, but his most striking experiment was made with a wooden cage, measuring 12 feet each way, covered with tin-foil, insulated and charged by a powerful electric machine. He carried his most delicate electroscopes into this cage. Large sparks and brushes were darting off from every part of the outer surface, but the philosopher and his sensitive instruments within the cage failed to detect the least electric influence.

Experiment 32.—Place a carrot horizontally upon an insulating support. Into one end of the carrot, stick a sewing-needle. Bring the electrified glass rod near the point of the needle without touching it. The – electricity of the carrot quietly escapes from the point to the rod and the carrot is charged with the + electricity that remains.

342. Density.—Experiments show that when a spherical conductor is charged, the electricity is evenly distributed over the surface, provided no other electrified body be near to affect the distribution by induction. The electric density (or number of electrical units per unit of area) is the same at every point. Experiments on an elongated cylinder, like the prime conductor of the electric machine, show that the density is greater at the ends. On an egg-shaped conductor, like that shown in Fig. 141, the density is greatest at the smaller end. *In general, the electric density is very great at any pointed part of a charged conductor.*

This density at a point may become so great that the electricity will escape rapidly and quietly, the air particles quickly carrying off the charge by convection. This explains the effect of pointed conductors, which plays so important a part in the action of electric machines. This property will be illustrated in several of the experiments of § 371. It is fundamental to the quiet action of lightning rods.

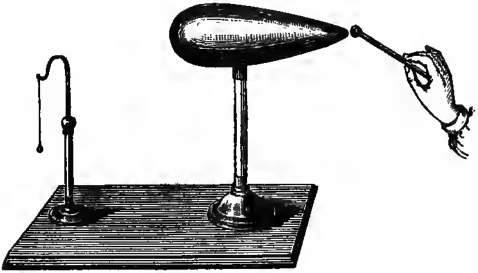


FIG. 141.

343. Electric Machines.—Machines have been made for developing larger supplies of electricity more easily than can be done with a rod of glass or sealing-wax or with the electrophorus. Each of them consists of one part for producing the electricity and another part for collecting it.

344. The Plate Electric Machine.—This instrument is represented in Fig. 142. It consists of an insulator (or electric), a rubber, a negative and a positive or prime conductor. The electric is a glass (or ebonite) plate, *A*, generally one, two or three feet in diameter. This plate has an axis, *B*, and handle, *C*, and is supported upon two upright columns. The rubber, *D*, is made of two cushions of silk or leather, covered with amalgam (see § 302, *a*). They press upon the sides of the plate and are supported

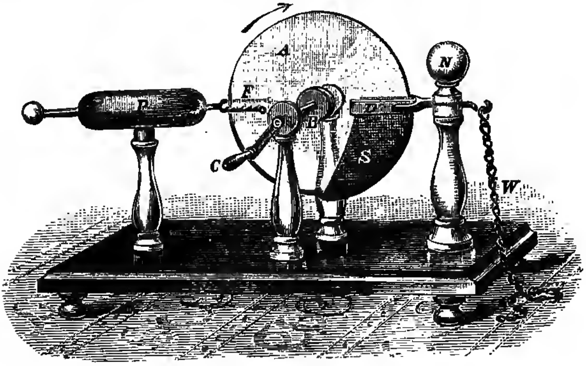


FIG. 142.

from the negative conductor, with which they are in electric connection. The negative conductor, *N*, is supported upon an insulating column and, when only positive electricity is desired, is placed in electrical connection with the earth by means of a chain or wire, *W*. The prime conductor, *P*, is insulated. One end of the prime conductor terminates in two arms, *F*, which extend one on either side of the plate. These arms, being studded with points projecting toward the plate, are called *combs*. The teeth of the combs do not quite touch the plate. A silk bag, *S*, is often supported so as to enclose the lower part of the plate. All parts of the instrument except the teeth of the combs are carefully rounded and polished, sharp points and edges being avoided to prevent the escape of electricity as already explained. This avoiding of points and edges is to be regarded in all apparatus for use with electricity of high potential.

(*a.*) The pupil may make a plate machine without much expense. A glazier will cut for him a disc of plate glass, possibly from a fragment on hand. The edges of this disc may be rounded on a wet grindstone. A hole may be bored in the middle with a round file kept moistened with a solution of camphor in turpentine. The conductors, *N* and *P*, may be made of wood covered with gold-foil or Dutch leaf and supported on pieces of stout glass tubing. The prime conductor may well have two such supports. The arms may consist of two stout wires thrust into the end of a prime conductor, their free ends being provided with knobs of lead or other metal. The combs may be made by soldering pin points to one side of each arm. See that the gold-foil makes actual contact with the metal arms. See that all metal parts except the pin points are polished smooth. The columns that support the plate may be made of seasoned wood. The part of the handle to which the hand is applied may be made of glass or insulated by covering it with rubber tubing.

345. Operation of the Plate Machine.—The plate is turned by the handle. Electric separation is produced by the friction of the rubbers. The + electricity of the rubber and negative conductor passes to the plate; the — electricity of the plate passes to the rubber and negative conductor. The part of the plate thus positively charged passes to the combs of the prime conductor. The + of the plate acts inductively upon the prime conductor, polarizes it, repels the + and attracts the — electricities. Some of the — electricity thus attracted streams from the points of the combs against the glass, while some of the + electricity of the glass escapes to the prime conductor. This neutralizes that part of the plate, or restores its electric equilibrium, and leaves the prime conductor positively charged. As each successive part of the plate passes the rubber, it gives off — electricity and takes an equal amount of + ; as it passes between the combs it gives off its + electricity and takes an equal amount of —. The rubber and negative conductor are kept in equilibrium by means of their connection with the earth, "the common reservoir." As the plate revolves, the lower part, passing from *N* to *P*, is positively charged; the upper part, passing from *P* to *N*, is neutralized. If negative electricity be desired, the ground connection is changed from *N* to *P* and the charge taken from *N*.

346. The Dielectric Machine.—This instrument is represented in Fig. 143. Two plates of vulcanite (ebonite), *A* and *B*, overlap each other without touching and revolve in opposite directions. The upper plate is made to revolve much more rapidly than the lower by means of the pulleys shown at the right of the figure. The prime conductor and the axes of the two plates are carried by two insulating pillars. From the prime conductor, a comb is presented to the upper part of the upper plate. Another comb is presented to that part of *A* which is overlapped by the upper part of *B*. This comb is connected by a universal joint at *e* with a discharging rod and ball, which may be brought near the end of the prime conductor or turned away from it. The rubbers and the lower comb are to be in electrical communication with the earth. The general arrangement is clearly set forth in the figure.

347. Operation of the Dielectric Machine.—The plate, *B*, is turned directly by the handle and the plate, *A*, indirectly by the aid of the pulley. The plate, *B*, is negatively electrified by friction with the rubber and thus acts by induction upon the lower part of *A*, which is thus polarized. The + of this part of *A* is bound by the attraction of the — of *B*, while the — of *A* is repelled, escapes by the lower comb and is replaced by + from the earth through the lower comb and its ground connection. This part of *A*, thus positively charged, is soon removed from the inducing body and the + charge, *bound* by *B*, is set free. It then comes to the upper comb, polarizes it and the prime conductor and exchanges some of its own + for an equal amount of — from the prime conductor. This neutralizes that part of the upper plate and leaves the prime conductor positively charged. As each successive part of *A* passes the lower comb, it gives off — electricity and takes an equal amount of + ; as it passes the upper comb, it gives off + electricity and receives an equal amount of —. The charge of *B* is continually maintained by friction with the rubber. When the discharging rod and ball are brought near the prime conductor, as shown in the figure, a rapid succession of sparks is produced, owing to the recombination of the separated electricities. If another body is to be charged from the prime conductor, the ball and rod may be turned aside. The efficiency of this machine is greater than that of the plate

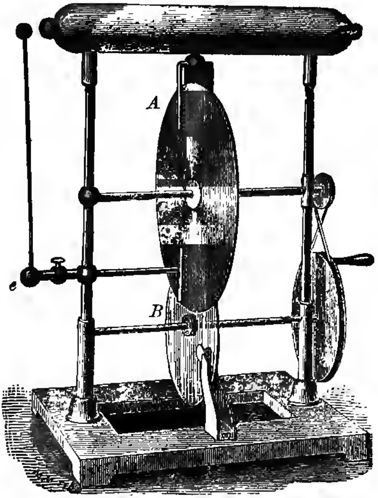


FIG. 143.

or cylinder machine. It is less affected by atmospheric moisture and is more compact, but the vulcanite plates seem to deteriorate with use. They should be washed occasionally with ammonia water and rubbed with paraffin oil. Machines of similar construction, but having glass plates, are made.

348. The Holtz Electric Machine.—This instrument is represented in Fig. 144. It contains two thin, circular plates of glass, the larger of which is held fast by two fixed pillars. The smaller plate revolves rapidly very near it. There are two holes in the fixed plate near the extremities of its horizontal diameter. To the sides of these openings are fastened paper bands called *armatures*. The armatures point in a direction opposite to that in which the revolving plate moves. Opposite these armatures and separated from them by the revolving plate, are two metallic combs, connected respectively with the two knobs and Leyden jars shown in the front of the picture. One of these knobs is carried by a sliding rod so that their distance apart is easily adjusted. When this machine works well, it gives results superior to either of those previously mentioned. It is, however, peculiarly subject to atmospheric conditions and is generally considered extremely capricious.

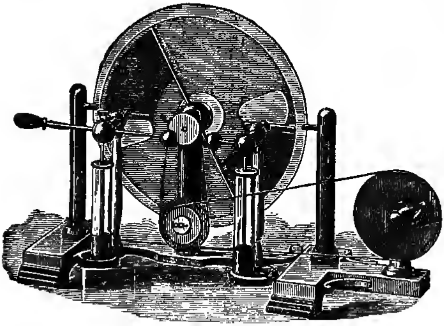


FIG. 144.

349. Action of the Holtz Machine.—To understand the action of this machine requires careful attention. The knobs are placed in contact and a small initial charge is given to one of the armatures by some charged body, as a piece of vulcanite or a glass rod. The handle is then turned, the effort necessary to keep up the motion increasing rapidly. The knobs are then separated and a series of discharges takes place between them.

(*a.*) Suppose a small + charge to be imparted at the outset to the right armature. This charge acts inductively across the revolving plate upon the metallic comb, repels + electricity through it and leaves the points negatively electrified. They discharge negatively electrified air upon the front surface of the movable plate; the repelled + charge passes through the brass rods and balls and is discharged through the left comb upon the front side of the movable disc. Here it acts inductively upon the paper armature, causing that part of it which is opposite itself to be negatively charged and repelling a + charge into its farthest part, *viz.*, into the armature. This, being bluntly pointed, slowly discharges a + charge upon the *back* of the movable plate. When the plate is turned round, this + charge on the back comes over from the left to the right side and, when it gets opposite the comb, increases the inductive effect of the already existing + charge on the armature and, therefore, repels more electricity through the brass rods and knobs into the left comb. Meantime the — charge, which we saw had been induced in the left armature, has in turn acted on the left comb, causing a + charge to be discharged by the points upon the front of the plate and, drawing electricity through the brass rods and knobs, has made the right comb still more highly —, increasing the discharge of negatively electrified air upon the front of the plate, neutralizing the + charge which is being conveyed over from the left. These actions result in causing the top half of the moving disc to be positively electrified on both sides and the bottom half of the disc to be negatively electrified. The charges on the front serve, as they are carried round, to neutralize the electricities let off by the points of the combs while the charges on the back, induced respectively in the neighborhood of each of the armatures, serve, when the rotation of the plate conveys them round, to increase the inductive influence of the charge on the other armature. Hence, a very small initial charge is speedily raised to a maximum, the limit being reached when the electrification of the armatures is so great that the loss of electricity at their surface equals the gain by convection and induction.

Note.—Other forms of electric machines are made. One of the latest of these, known as the Toepler-Holtz, is very compact and efficient and remarkably free from the limitations of atmospheric conditions. It may be described as a continuously acting electrophorus (§ 227). A very good one may be bought for $25 or more. One should be provided for the school *in some way* if possible. Any electrical machine should be free from dust and perfectly dry when used. It should be warmer than the atmosphere of the room, that it may not condense moisture from the surrounding air. The drier the atmosphere, the better will be the action of the machine.

EXERCISES.

1. How can you show that there are two opposite kinds of electricity?

2. How would you test the *kind* of electricity of an electrified body?

3. Quickly pass a rubber comb through the hair and determine whether the electricity of the comb is positive or negative.

4. Why do we regard the two electric charges produced simultaneously by rubbing together two bodies as being of opposite kinds?

5. Why is it desirable that a glass rod used for electrification be warmer than the atmosphere of the room where it is used?

6. Electrify one insulated egg-shell conductor (§ 332, *b*). Bring it near a second conductor but not in contact with it. Touch the second egg-shell with the finger. (*a.*) Experimentally, determine whether the second egg-shell is electrified or not. (*b.*) If you find that it is, what word explains the method of charging? (*c.*) If the second egg-shell is charged, will its potential and the potential of the first be of the same or of opposite signs?

7. (*a.*) In § 323, *b*, it is directed that an electrified body be brought "near" the knob of the gold-leaf electroscope. Why not *touch* the knob with the charged body? (*b.*) Why do not the gold leaves diverge immediately after touching the knob with the finger as there directed? (*c.*) If the electrified body being tested had a + charge, is the charge of the gold leaves + or − ? Explain.

8. (*a.*) What is a proof-plane? (*b.*) An electroscope? (*c.*) Describe one kind of electroscope. (*d.*) Another kind.

9. (*a.*) Define *electrics, conductors* and *insulators.* (*b.*) Explain electric induction.

10. (*a.*) If a metal globe suspended by a silk cord be brought near the prime conductor of an electric machine in action, feeble sparks will be produced. Explain. (*b.*) If the globe be held in the hand, stronger sparks will be produced. Explain.

11. Twist some tissue paper into a loose roll about six inches long. Stick a pin through the middle of the roll into a vertical support. Present an electrified rod to one end of the roll and thus cause the roll to turn about the pin as an axis. Give this piece of scientific apparatus an appropriate name.

12. (*a.*) Prepare two wire stirrups, *A* and *B*, like those shown in Fig. 121 and suspend them by threads. Electrify two glass rods by rubbing them with silk and place them in the stirrups. Bring *A* near *B*. Notice the repulsion. (*b.*) Repeat the experiment with two sticks of sealing-wax that have been electrified by rubbing with flannel. Notice the repulsion. (*c.*) Place an electrified glass rod in *A* and an electrified stick of sealing-wax in *B*. Notice the attraction. Give the law illustrated by these experiments.

13. Two small balls are charged respectively with + 24 and − 8 units of electricity. With what force will they attract one another when placed at a distance of 4 centimeters from one another?

Ans. 12 dynes.

14. If these two balls are then made to touch for an instant and then put back in their former positions, with what force will they act on each other? *Ans.* Repulsion of 1 dyne.

Experiment 33.—Hang a negatively charged pith ball inside a dry glass bottle. Bring an electrified glass rod to the outer side of the bottle. The pith ball will rush to the side of the bottle nearest the rod because of the attraction between the opposite electricities.

Experiment 34.—Paste a piece of tin-foil, two or three inches square, on the middle of each face of a pane of glass. Hold a finger on one of the metallic coats while the other coat is held, for a short time, in contact with the prime conductor of an electric machine in operation. Remove the pane and place it on edge without touching both coats at the same time. Although both coats are oppositely charged (§ 334), they may be touched in succession without any shock. When both are touched at the same time, the shock is greater than would have been received from the prime conductor by which *this condenser* was charged.

350. Condensation of Electricity.—Two suspended pith balls oppositely charged attract one another across the intervening air. They attract mutually even when a plate of glass is held between them although neither the balls nor their electric charges can pass through the glass. In the case of the pane of glass with its two tin-foil coats, or in the similar case of two metallic plates, *A* and *B*, separated by a layer of dry air or other non-conductor, *C*, as shown in Fig. 145, the two charges are "bound," each by the attraction of its opposite on the other side of the pane. It is found that two such coats may be charged much more strongly than either one could be if the opposite coat were wanting. If a third plate like *B*, *but hav-*

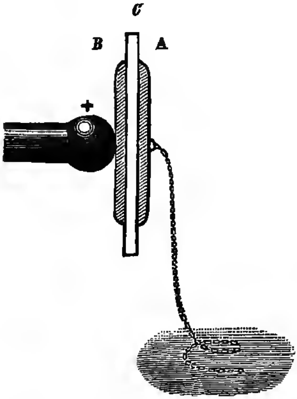


FIG. 145.

ing no opposite plate like A, be connected with *B* by a copper wire and the middle of the wire brought into contact with the prime conductor, nearly the whole charge will go to *B* and very little to the third plate. *The capacity of a charged conductor is greatly increased by bringing it near a second charged conductor oppositely charged.* Its capacity being thus increased, a greater quantity of electricity must be put into it to raise it to as high a potential. Such a method of increasing the quantity of electricity that a conductor may receive without raising its potential is called the condensation or accumulation of electricity.

351. Electric Condensers.—An apparatus for collecting a large quantity of electricity at a moderate potential, as just described, is called an electric condenser.

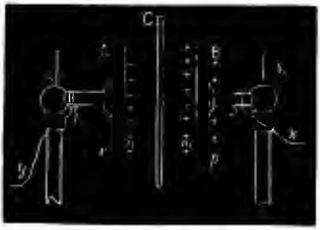


FIG. 146.

(*a.*) Let *A* and *B*, Fig. 146, represent two insulated metallic plates about six inches in diameter, separated by *C*, a plate of glass somewhat larger. Let each metallic plate have an electric pendulum, *a* and *b*. Remove *A* and connect *B* with the conductor of the electric machine, by means of the wire, *x*. The divergence of *b* shows the presence of free electricity. Connect *A* with the ground by the wire, *y*, and place it in position as represented. By the inductive influence of *B*, the − electricity of *A* is drawn to the surface, *n*, while the + escapes by *y*. But this − electricity at *n* attracts the + of *B* largely to the surface *m* and holds it there as *bound* electricity, thus increasing the electrical density at that surface. This change is shown by less divergence of *b*. Consequently, *B* can receive more electricity from the machine, which will, in turn, attract more − electricity to *n*. This further supply will, in turn, bind more of the + electricity of *B* at *m*. In this way, a large quantity of + electricity may be accumulated at *m* and a large quantity of − at *n*. This accumulation may thus go on until the potential at the surface, *p*, is equal to that of the machine, as it was when *A* was absent. Interrupting communication by *x* and *y*, both plates are charged. The vertical pendulum, *a*, shows no *free* electricity, the electricity of *A* being all bound at *n*; the pendulum at *b* shows some free electricity, although the greater part of the electricity of *B* is bound at *m*. Remove *A* and *B* from each other and the bound electricity of each is set free and both *a* and *b* fly out as the discs are separated. The pith balls thus seem to indicate that the discs are more highly electrified when they are thus separated, but no additional charge has been given to either *A* or *B*. The fact is that *while B was near A, the capacity of B was largely increased. On moving it away from A, its capacity was diminished and the same quantity of electricity electrified it to a higher potential than before. The presence of an earth connected plate near an insulated conductor largely increases the electric capacity of the latter, enabling it to condense electricity upon the surface nearest the opposing plate, at which surface the electrical density becomes very great.*

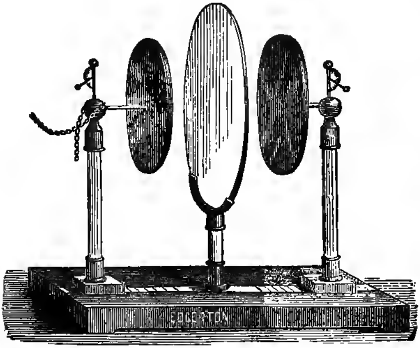


FIG. 147.

(*b*.) If *A* and B are pushed up close to *C*, the decrease of distance will work an increase of the inductive action and a still larger quantity may be accumulated in the plates. *Thus, the capacity of a condenser depends, in part, upon the nearness of the plates to each other.*

352. Dielectrics and Specific Inductive Capacity.—Substances that permit inductive electric influences to act across or through them as just described are called *dielectrics*. All dielectrics are insulators, but equally good insulators are not always equally good dielectrics. Glass is a better dielectric than ebonite and ebonite is better than air. The capacity of a condenser is greater when the dielectric is glass than it is when the dielectric is air. *The ratio of the capacity in the former case to the capacity in the latter case is called the specific inductive capacity (or specific inductivity) of glass.* Air (at 0° C. and 760 *mm.*) is taken as the standard, its specific inductive capacity being unity.

(*a.*) The old idea that electric induction is "action at a distance" is wholly disproved by the fact that different substances have different specific inductive capacities, for it is evident that the dielectric itself is concerned in the process. Otherwise, all media would allow induction to take place across them with equal facility.

(*b.*) The specific inductivity (sometimes called dielectric capacity) assigned to various substances by different observers varies widely. Gordon gives the following results:

Air	1.00	Ebonite	2.284	Shellac	2.74
Paraffin (solid)	1.9936	Gutta percha	2.462	Glass, from	3.013
India rubber	2.22	Sulphur	2.58	" to	3.258

Schiller gives the specific inductivity of white mirror glass as 5.88 to 6.34.

353. The Leyden Jar.—The most common and, for many purposes, the most convenient form of condenser is the Leyden jar. This consists of a glass jar, coated within and without for about two-thirds its height with tin-foil, and a metallic rod, communicating by means of a small chain with the inner coat and terminating above in a knob. The upper part of the jar and the cork which closes the mouth of the jar and supports the rod are generally coated with sealing-wax or shellac varnish to lessen the deposition


FIG. 148.

of moisture from the air. The inner coat represents the collecting plate, *B*; the glass jar, the insulating plate, *C*; the outer coat, the condensing plate, *A*, of Fig. 146.

(*a.*) Select a candy or fruit jar of greenish glass; paste tin-foil within and without, as above described, using flour paste; thrust a wire through a dry cork; bend the wire so that, when the cork is in its place, the wire shall touch the tin-foil on the inside of the bottle without tearing it; solder the upper end of the wire to a smooth button or thrust it into a lead bullet; charge *your Leyden jar* with a few sparks from the electrophorus and take a shock.

354. Charging the Leyden Jar.—To charge the jar, hold it in the hand, as shown in Fig. 149, and bring the knob near the prime conductor of an electrical machine that is in action or into contact with it.

(*a.*) The + charge thus developed on the inner coat acts inductively through the glass, repelling the + electricity which escapes through the hand to the earth and binding its − electricity to the surface in contact with the glass. This "bound" negative electricity of the outer coat, in turn, binds the positive of the inner coat, which then may receive a further charge and so on. The inner coat will receive a much greater quantity of electricity than it possibly could were it not for the attraction of its opposite on the outer coat. If, instead of holding the outer coat in the hand, the jar be supported upon a pane of glass so that the repelled electricity of the outer coat cannot escape, the jar cannot be very intensely charged.

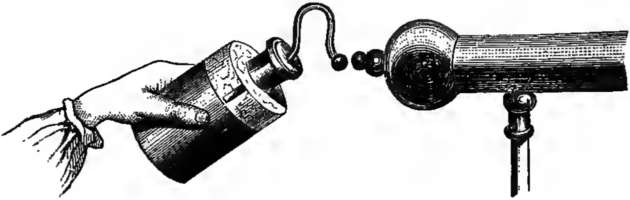


FIG. 149.

(*b.*) Thus we see again that the capacity of a conductor is greatly increased when it is placed near a conductor charged with the opposite kind of electricity. Its capacity being increased, it can receive a greater quantity of electricity without any increase of potential. Of course, the potential of the charged jar cannot exceed that of the prime conductor or other charging body.

355. Discharging the Leyden Jar.—If the jar be of good glass, dry and free from dust, it will retain its charge for hours. But if a path be provided by which the opposite and mutually attracting electricities can flow together, they will do so and the jar will be instantaneously and almost completely discharged. The jar might be discharged by touching the knob with the finger, the separated electricities coming together through the person of the experimenter and the earth. In this case, the experimenter will feel a "shock." If the charge be intense, the shock will be painful or even dangerous. It is better to use a "discharger," two forms of which are represented in Fig. 150. This consists of two metal arms hinged together, bearing knobs at their free ends and carried by insulating handles. The outer coat of the jar should be touched first. Why?

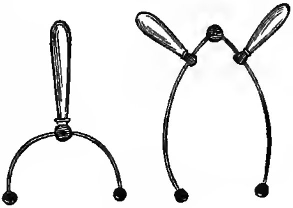


FIG. 150.

(*a.*) A good discharger may be made by passing a piece of stout, copper wire, about a foot long, through a piece of rubber tubing and providing a metal knob for each end of the wire. The flexibility of the wire avoids the necessity for a hinged joint.

356. The Residual Charge.—If a Leyden jar be charged, discharged and left for a little time to itself, it will be found that a small, second spark can be obtained.

There is a residual charge which seems to have soaked into the glass. The return of the residual charge is hastened by tapping the jar. The amount of the residual charge varies with the time that the jar has been left charged; it also depends on the kind of the glass of which the jar is made. (See Appendix J.)

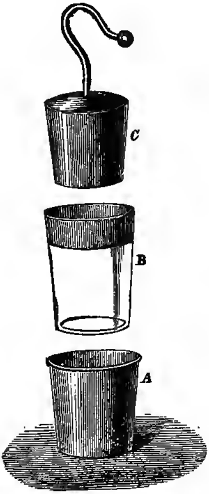


FIG. 151.

357. The Leyden Jar with Movable Coats.—This piece of apparatus is represented by Fig. 151. The upper part of the glass jar, *B*, is coated with shellac varnish. The three parts being placed together in proper order, *B* within *A* and *C* within *B*, the jar is charged in the usual manner. The inner coat, *C*, is then removed with a glass rod and touched with the hand to discharge it fully. *B* is then lifted out from *A* and the outer coat fully discharged. The three parts are then put together again and found to be able to give nearly as strong a spark as at first. This seems to indicate that the charge rests upon the surfaces of the glass rather than upon the surfaces of the coats. If, when the charged jar is in pieces, the thumb be placed on the outer surface of the glass and the forefinger of the same hand on the inner surface, a very slight shock is perceptible. The oppositely charged glass molecules that come into actual contact with thumb and finger respectively are discharged. By changing the position of the thumb and finger, successive little shocks may be felt as successive portions of the inner and outer surfaces of the glass are discharged. The inner coat furnishes a means for the simultaneous discharge of the inner layer of glass molecules; the outer coat does the same for the outer layer of glass molecules. Thus all or nearly all of the electrified glass molecules may be discharged simultaneously instead of successively.

358. The Leyden Battery.—The effect that may be produced with a Leyden jar or other condenser depends upon the size of the coats, the thinness and the inductive capacity of the glass. But a large jar is expensive and requires great care; thin glass is liable to perforation by the condensed and strongly attracting electricities of its two coats. To obviate both of these difficulties, a collection of jars is used. When their outer coats are in electric communication, which may be secured by placing them in a tray the bottom of which is covered with tin-foil, and their inner coats are connected by wires or metal strips passing from rod to rod, or from knob to knob, the apparatus is called a Leyden or electric battery. "Toughened glass" is less easily pierced than ordinary glass. Hence, Leyden jars made of it may be made thinner and, consequently, will hold a greater charge than otherwise. The battery is charged and discharged in the same way as a single jar. Great care is needed, for if the discharge

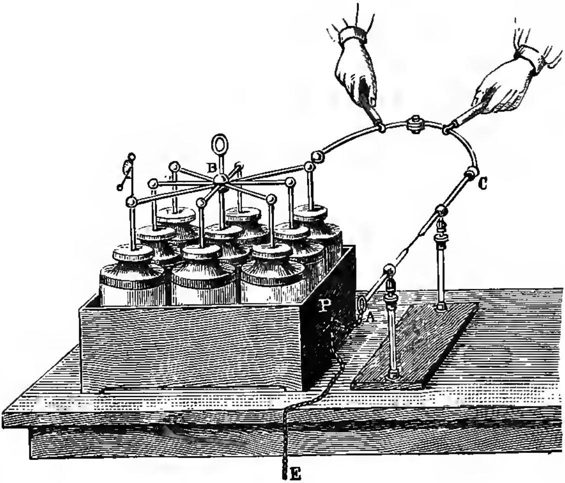


FIG. 152.

were to take place through the human body the result would be serious and possibly fatal. The "universal discharger," as employed with the Leyden battery, is shown at *AC* in Fig. 152. (See Exp. 56.)

(*a.*) The horizontal rods of the universal discharger may be supported by passing them through corks in the mouths of two bottles. When a table is wanted for the support of bodies to be operated upon by the discharge, it may be made by placing a small plate of glass upon the open mouth of a bottle of the same height as those that carry the rods and placing the third bottle between the other two.

359. The Farad.—The farad is the capacity of a condenser that will be raised to a potential of one volt by a charge of one coulomb of electricity (§§ 382, 387). Such a condenser would be too large to be constructed. *The micro-farad* (=0.000001 farad) *is, therefore, chosen as the practical unit of electrical capacity.* The capacity of three miles of an Atlantic cable is about one micro-farad. A micro-farad condenser contains about 3,600 square inches of tin-foil. A farad equals 10^{-9} of an absolute unit of capacity (§ 330). See Appendix M (5).

(*a.*) A coulomb in a farad gives a volt.

$$\text{Farads} = \frac{\text{Coulombs}}{\text{Volts.}}.$$

360. Submarine Cable Condensers.—An ocean cable forms a condenser, the water forming the outer coating; the conducting wire, the inner coating; while the insulating layers of gutta-percha correspond to the glass of the Leyden jar. When, for example, one end of a submerged cable is connected to the + pole of a powerful battery, + electricity flows into it. Before any signal can be received at the other end, enough electricity must flow in to charge the cable to a considerable potential, an operation which may, in the case of long cables, require some seconds. It is a serious obstacle to signalling with speed through the Atlantic cables.

(*a*.) Imagine a mile of insulated cable wire to be coiled up in a tub of water (Fig. 153), one end, *N*, being insulated. The other end is joined up through a long coil galvanometer, *G*, to the + pole of a large battery, whose — pole is joined by a wire to the water in the tub. As soon as this is done, the needle of the galvanometer will show a violent deflection, + electricity rushing through it into the interior of the cable and a — charge being accumulated on the outside of it where the water touches the gutta-percha. The flow will go on, though diminishing, until the cable is fully charged, taking, perhaps, an hour. Now remove the battery and close the circuit. The charge in the cable will rush out through the galvanometer, which will show an opposite deflection. The charge will continue "to soak out" for a long time.

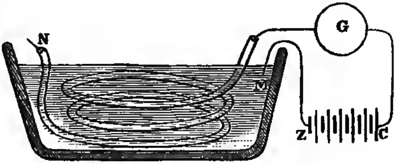


FIG. 153.

361. Modes of Discharge.—An electrified conductor may be discharged in at least three ways, *viz.*, by the *disruptive* discharge, by the *convective* discharge and by the *conductive* discharge. The discharge in any of these ways is accompanied by a transformation of energy. Sound, light, heat, chemical action and other phenomena are produced.

Experiment 35.—Present a knuckle of the hand or a metal knob to the prime conductor of an electric machine and "draw sparks" therefrom. (See Fig. 169.) For short distances, *the spark* is straight. If the distance be made somewhat greater, the spark takes a sinuous and forked form as though floating dust particles served as stepping-stones and rendered a crooked path the easiest. If the charge be very powerful, the spark will take the zigzag form so familiar in the lightning-stroke. When the machine is vigorously worked in the dark, the apparently continuous discharge into the air produces a luminous appearance at the ends of the conductor. This appearance, known as a *brush*, may be improved by holding a large, smooth, metal globe at a distance a little too great for the passage of a spark. When the discharge takes place from the rounded end of a wire extending from the conductor, a quiet, phosphorescent *glow*, as shown in Fig. 154, will often appear at and near the end of the wire.

FIG. 154.

362. The Disruptive Discharge.

362. The Disruptive Discharge.—A discharge of electricity taking place suddenly through a non-conductor is called a disruptive discharge, *e.g.*, the spark and brush drawn from an electric machine in action. The glow is either a continuous discharge or one of exceedingly small period. Perhaps, it is a high order of convective discharge.

Experiment 36.—Attach a pointed wire to the prime conductor of the electric machine. The flame of a candle held near will be blown away, as shown in Fig. 155. If the candle be placed upon the prime conductor and a pointed conductor be held in the hand near the candle, the flame will still be blown away.

363. The Convective Discharge.—When electricity of high potential accumulates with so great a density as to electrify the neighboring particles of air which, driven by electric repulsion, fly off carrying

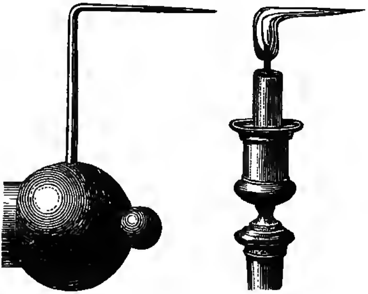


FIG. 155.

part of the charge with them, we have what is called the convective discharge. Such discharges are best manifested in gases at low pressure, in tubes exhausted by an air-pump. (Exp. 70.)

364. The Conductive Discharge.—The flow of a continuous current of electricity constitutes the conductive discharge. When electricity flows through a wire from the prime conductor of an electric machine to the rubbers or from the positive pole of a voltaic cell or battery to the negative, we have a conductive discharge. It will be considered in the section especially devoted to voltaic electricity.

365. Atmospheric Electricity.—The phenomena of atmospheric electricity are of three kinds:

1. A continual slight electrification of the air, best observed in fair weather.
2. The familiar phenomena of thunder storms.
3. The Aurora Borealis.

366. The First Kind.—During fair weather, the air above the surface of the earth is usually electrified positively, a negative electrification being extremely rare. In stormy weather, it is more often — than + and frequently changes from one kind to the other several times in an hour. The higher up we go to observe the usual + electricity of the air, the higher its potential is found to be. The evaporation of water by the sun's heat and the friction of moving masses of air probably contribute to the presence of atmospheric electricity.

367. Thunder Storms.—We have already seen (§ 341) that a solid conductor can not be charged throughout its substance, the charge residing upon the surface. The same is true of liquids, but aëriform bodies may be charged bodily, the individual molecules being so much more widely separated. Dry air being a poor conductor, the air particles discharge their electricity into each other slowly and with difficulty. The electricity thus prevented from accumulating has a low potential and, hence, gives few manifestations of its presence. The minute particles of water floating in the air being better conductors than the air itself become more highly charged. As they fall and unite, the potential of their charges increases.

(*a.*) "Suppose eight small drops to join into one. That one will have eight times the quantity of electricity distributed over the surface of a single sphere of twice the radius and, therefore, of twice the capacity (for the electrical capacities of spheres are proportional to their radii) of the original drops." The capacity being thus increased only two fold while the quantity is increased eight fold, the potential becomes four times as great. Thus the potential of a cloud may rise by the union of electrified drops.

368. Lightning.—When an electrified cloud floats over the earth, separated from it by a layer of insulating air, the inductive influence of the cloud renders the ground beneath oppositely electrified. Then the cloud, ground and insulating air correspond respectively to the inner and outer coatings and the insulating glass of a Leyden jar. As the charge of a Leyden jar may be made so intense that the mutual attraction of the separated electricities will result in their rushing together and thus piercing the jar (§ 358), so the charge of a cloud may become sufficiently intense to overcome the resistance of the air and a lightning stroke ensues. Two clouds charged with opposite electricities may float near each other. Then they, with the intervening air, may be looked upon as constituting a huge Leyden jar. Thus, we may see the lightning leaping from cloud to earth, or from cloud to cloud. Such electric sparks are sometimes more than a mile in length, showing a difference of potential greater than that of 3,000,000 Daniell's cells. The duration of the spark or flash is not more than 0.00001 of a second. The danger from any lightning stroke has passed when we hear the crash. The identity of lightning with electricity, though long suspected, was first proved by Franklin's famous kite experiment.

Experiment 37.—Bring the point of a knife-blade near the conductor of an electric machine in operation and *notice the instant cessation of sparks.* The quiet passage of electricity from the earth neutralizes the charge of the conductor and restores the electric equilibrium. In the same way, a lightning-rod tends to restore the electric equilibrium of the cloud and prevent the dangerous discharge.

369. Lightning-Rods.—The value of lightning-rods depends upon the tendency of electricity to follow the best conductor and upon the effect of pointed conductors upon electrical density (§ 342). The lightning-rod should, therefore, be made of a good conductor; copper is better than iron. It should terminate above in one or more points, tipped with some substance that may be corroded or fused only with extreme difficulty. Platinum and iridium are metals that satisfy these conditions very well. The rod should extend above the highest point of the building in order to offer the electricity the easiest path to the ground. It is important to have each projecting part of the building, as chimneys, towers and gables, protected by a separate rod. All metal work about the roof or chimneys should be connected with the rod. The rod should afford an unbroken connection; the joints, if there be any, should be carefully made. The rod should terminate below in water, or in earth that is *always* moist. It is well to connect it with underground water-pipes when possible or with a large metal plate. *Personal attention* should be given to this matter when the rod is put up as, being under ground and out of sight, this part of the rod is not easily inspected subsequently. *A rod having a blunted tip, a broken joint or terminating in dry earth is more dangerous than no rod at all. Lightning-rod insulators are undesirable.*

(*a.*) The greatest value of a lightning-rod is due to its quiet work in the *prevention* of the lightning stroke. For this quiet but very valuable service, few persons ever give the rod any credit. Every leaf of the forest and every blade of grass is a pointed conductor acting in the same way.

(*b.*) There is some question as to the space protected by a rod, but the following is a good rule: The protected space is a cone having its apex at the tip of the rod and having a base the radius of which is equal to the height of the cone.

370. The Aurora Borealis.—The aurora borealis or "northern light" is frequently seen in northern regions; beyond the Arctic circle it is of almost nightly occurrence. Sometimes its streamers of light radiate like the ribs of a fan or form an arch across the northern sky, as shown in Fig. 156. But, as seen in this country, it more often appears as a few streamers of a pale tint. Similar lights are seen in south polar regions and are called *aurora australis.*

The atmosphere, in its upper strata, is highly rarefied and conducts electricity as do the rarefied gases in Geissler tubes (Exp. 70). There is little doubt that the aurora is due to electric discharges in this rarefied air. The appearance of an aurora is generally accompanied by a "magnetic storm" or irregular disturbance that affects all of the compass needles over a considerable part of the earth.

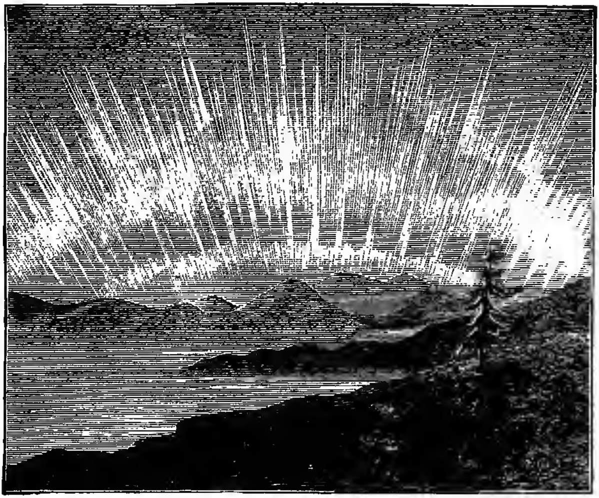


FIG. 156.

371. Apparatus and Experiments. — It is neither necessary nor very desirable that all of the following experiments be performed. Several of them involve the same principle; but one teacher may have one piece of apparatus and another, another piece. Additional experiments may be found in "The First Principles of Natural Philosophy," pp. 174–176.

Experiment 38.—Place a tin plate containing a handful of small bits of tissue paper upon the prime conductor of an electric machine. Work the machine and thus produce an imitation snow storm.

Experiment 39.—The "metallic plates and dancing images" are represented in Fig. 157. The images are made of pith. The upper plate is in communication with the prime conductor, the lower one, with the earth. When the machine is worked, the images dance in a very ludicrous manner. *Explain.* Pith balls may be substituted for the images, the resulting phenomena being known as "Volta's hail." The experiment may be simplified by electrifying the inner surface of a glass tumbler by rubbing it upon the knob of the prime conductor and placing the tumbler over some pith balls on the table.

FIG. 157.

Experiment 40.—Place a dozen pith balls or some bits of tissue paper on a table between two books about 2 inches (5 *cm.*) thick. Place a pane of glass upon the books as shown in Fig. 158. Rub the upper surface of the glass with the silk pad mentioned in § 302 (or a silk handkerchief) and notice the lively dance of the pith balls.

FIG. 158.

Experiment 41.—In the "electric chime," represented in Fig. 159, the outer bells are to be put into communication with the prime conductor; the central bell is in communication with the earth. The clappers are suspended by silk threads. Work the machine slowly; the bells will begin to ring. *Explain.*

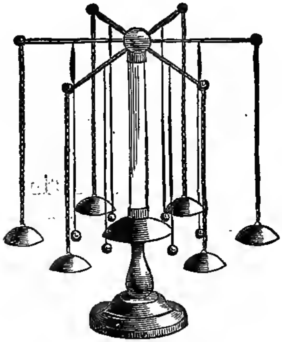


FIG. 159.

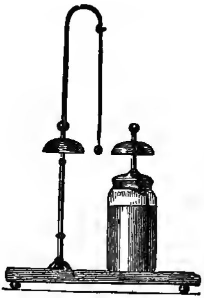


FIG. 160.

Experiment 42.—In the "Leyden jar and bells," shown in Fig. 160, the left-hand bell is in communication with the outer coat of the jar; the clapper is suspended by a silk thread. When the jar is charged and placed in position as represented, the bells begin to ring and continue to do so for a considerable time. *Explain.*

Experiment 43.—In the "electric swing," shown in Fig. 161, the boy is suspended by silk cords. One of the insulated knobs is in communication with the earth; the other with the prime conductor. When the machine is worked, the boy swings to and fro. *Explain.*

FIG. 161.

Experiment 44.—If a pupil hold a Leyden jar by the outer coat and, by a wire, connect the knob of the jar with the prime conductor, his knuckle will attract the balanced lath (Exp. 5) when the machine is worked. *Explain.*

Experiment 45.—Fasten a small paper kite by a linen thread to the prime conductor. When the machine is worked, the kite will float around the knob. *Explain.*

Experiment 46.—Fasten one end of a long, small, copper wire to the prime conductor. Near the other end of the wire, tie a silk cord and hang it from the ceiling or other support so that the end of the vertical part of the wire shall be at a convenient height. To this end of the wire attach a tassel about four or five inches long made of many strips of light tissue paper. Work the machine and the leaves will diverge. *Explain.* Extend toward it your clenched fist; the leaves seek the fist. *Explain.* Instead of your fist, hold a needle toward the tassel; it will be blown away. *Explain.* Hold the needle upright under the tassel. The strips will collapse. *Explain.*

Experiment 47.—Stand upon the insulating stool and place your left hand upon the prime conductor of the electric machine. Hold in your right hand a sewing-needle with the tip of the forefinger covering the end of the needle. Bring the right hand cautiously near the gold-leaf electroscope. Notice the divergence of the leaves. Now uncover the point of the needle and bring it near the electroscope. Notice the marked and immediate increase in the divergence of the leaves. *Explain.*

Experiment 48.—Place an "electric whirl" (which consists of a set of horizontal wire arms radiating from a pivot-supported centre, the pointed ends being all bent in the same direction) upon the prime conductor. Work the machine and the arms will revolve. (Fig. 162.) *Explain.*

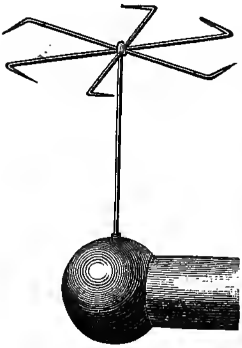


FIG. 162.

Experiment 49.—The "electric orrery," represented in Fig. 163, is a pretty modification of the "electric whirl." The short, balanced bar is provided with a pointed conductor to produce rotary motion upon its supporting pivot, which is one end of the long balanced bar. This longer bar is also provided with a pointed conductor and supported in turn upon a pivot, which may be attached to the prime conductor. When the machine is worked, the long bar revolves upon its fixed pivot; the short bar revolves upon its moving pivot.

FIG. 163.

Experiment 50.—Half fill a wide, glass vessel with water. Within this, place a glass beaker and fill it to the same level with water. By a wire, connect the water in the outer vessel with the earth; in similar manner, connect the water in the beaker with the electric machine. Give the handle of the machine a *single* turn. Dipping one finger into the outer water and another into the inner water, a shock is felt. *Explain.*

Experiment 51.—Let a pupil stand upon an insulating stool (a board supported by four warm tumblers will answer) and place his left hand upon the prime conductor. Let him, with his right hand, clasp the left hand of another pupil not insulated, their hands being prevented from actual contact by an intervening sheet of india-rubber cloth. After the machine has been worked a moment, let the insulated pupil remove his left hand from the prime conductor and clasp the free hand of his companion. At this moment of clasping hands, a shock will be felt. *Explain.*

Experiment 52.—Cover one knob of the discharger with gun cotton sprinkled with powdered rosin. When the Leyden jar is discharged with this discharger, the cotton and rosin are ignited.

Bring the covered knob of the discharger into contact with the knob of the jar with a quick motion.

Experiment 53.—The "electric bomb," represented in Fig. 164, may be made of ivory, heavy glass, or thoroughly seasoned wood. The ends of the two metal wires are rounded and placed a short distance apart. The bomb may be filled with gunpowder. One wire is connected by a chain with the outer coat of a charged Leyden jar. The other wire is to be connected with the inner coat by a *wet string* and the discharger. The spark between the ends of the two wires ignites the powder. Then try the experiment with air instead of powder.

Fig. 164.

Experiment 54.—Fig. 165 illustrates a method of igniting an inflammable liquid, like ether or alcohol, by the electric spark. Through the bottom of a small glass vessel, *a*, passes a metal rod, having a knob at its upper extremity. The lower end of this rod may be brought into electrical connection with the outer coat of a Leyden jar. Enough ether or alcohol is poured into *a* just to cover the knob. When the jar is discharged in the way shown in the figure, the spark ignites the liquid. If alcohol is used, it may have to be warmed to render the experiment successful.

Fig. 165.

Experiment 55.—Let a pupil, standing on an insulating stool, become charged by holding one hand on the prime conductor when the machine is in operation. If he then bring his knuckle to a metal burner from which a jet of gas is issuing, a spark will pass between the knuckle and the burner, igniting the gas. An Argand or Bunsen burner answers well for this experiment. The experiment may be modified by using, instead of the knuckle, an icicle held in the hand. The gas burner may be replaced by a pupil (not insulated) holding a spoonful of ether or of chloroform which readily gives off an easily combustible vapor.

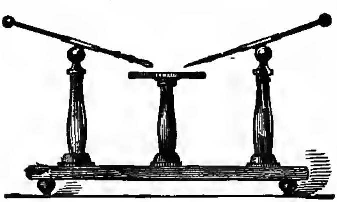


FIG. 166.

Experiment 56.—The "universal discharger," shown in Fig. 166, consists of a glass table and two insulated metal rods. (See § 358 *a.*) Balls, points and pincers are provided for use at the adjacent ends of the rods which are supported upon sliding and hinged joints, so that they may be easily placed in any desirable position. Cover the adjacent ends of the two rods with metal balls and place them upon the glass table, a small distance apart. Connect the balls by a very fine wire. One of the rods is to be connected by a wire or chain with the outer coats of a powerful battery; the other rod is to be connected, by the discharger, (Fig. 150) with the inner coats of the battery. The current thus passed along the fine wire may heat it to incandescence, melt or even vaporize it.

Experiment 57.—Prick a profile portrait of Franklin or some other design in a sheet of thin card board. Paste two pieces of tin-foil to the ends of the card and join them with a piece of gold leaf placed over the pricked design. Place a piece of white paper or silk on the other side of the card and have the whole tightly screwed up between two boards, leaving the edges of the tin-foil strips accessible. Discharge a Leyden battery through the gold leaf, thus volatizing it, sending the disintegrated particles through the holes in the card board and obtaining an impression of the portrait.

Experiment 58.—Fig. 167 represents "Volta's pistol," which consists of a metal vessel through one side of which passes an insulated metal rod with knobs at both ends. The knob at the inner end of this rod is near the opposite wall, so that a spark may easily be made to pass between the knob and the body of the pistol. The pistol being filled with a mixture of illuminating gas and common air in equal volumes or with oxygen and hydrogen in the proportion of one volume of the former to two of the latter and, the mouth being closed by a cork, the passage of the spark brings about a chemical union of the mixed gases, a violent explosion ensues and the cork is thrown some distance. The spark may be produced by holding the pistol in the hand and bringing the outer knob near the prime conductor; or the pistol may be suspended from the prime conductor by a wire or chain and the pistol then touched with the hand. The pistol may also be fired by means of the electrophorus.

FIG. 167.

Experiment 59.—On the glass table of the universal discharger (Fig. 166), place a piece of wood and bring the *knobs* of the sliding rods against its ends so that the line joining the knobs shall be in the direction of the fibers of the wood. Through the apparatus thus arranged, discharge a powerful Leyden jar battery. The piece of wood will be torn in pieces.

Experiment 60.—Support a pane of glass upon a glass cylinder, in the axis of which is a pointed conductor that just touches the pane. On the upper side of the pane directly over this pointed conductor, place a drop of oil to prevent the spark from gliding over the surface of the glass instead of passing through. From an in-

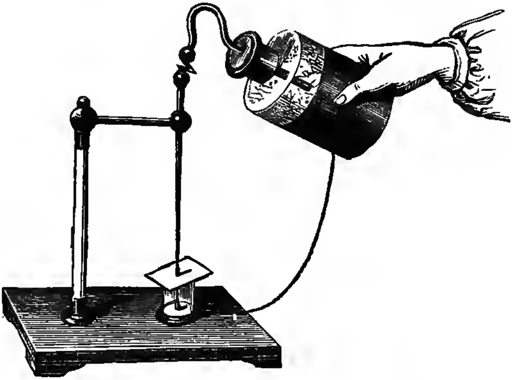


FIG. 168.

sulated support, lower a second pointed conductor until it touches the pane at the oil. Through these two pointed conductors (Fig. 168), discharge a Leyden jar *or battery.* Unless the glass is *very thin,* a single jar will not be sufficient. If the experiment fails the first time, do not use the same piece of glass for the second trial. A plate of glass, 6 *cm.* thick, has been pierced by means of a powerful induction coil.

Experiment 61.—With corks, plug the ends of a glass tube filled with water. Through the corks, introduce copper wires until the ends in the water are within a quarter of an inch of each other. Through these wires, discharge a Leyden jar. The mechanical shock due to the repulsion of the electrified water molecules will often break the tube.

Experiment 62.—Charge a Leyden jar. In discharging it, hold a stiff card between the knob of the jar and the knob of the discharger. A hole will be pierced through the card. By the side of this hole in the card, make another with a pin. Any one can tell

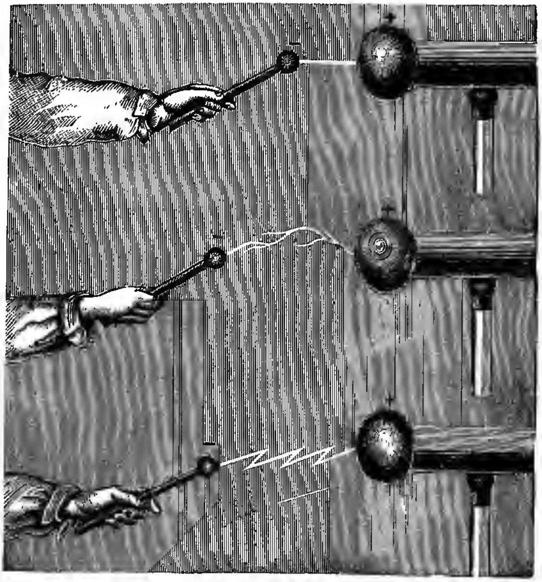


FIG. 169.

by examination of the pin-hole from which side of the card it was pierced; it is burred on only one side. Not so with the perforation made by this discharge; *it is burred on both sides.*

Experiment 63.—One of the inevitable experiments with an electric machine consists in "drawing sparks" from the conductor by the hand (Fig. 169). When the potential of the separated electricities becomes sufficient to overcome the resistance of the intervening air, they recombine with a sharp, explosive sound and brilliant flash of light. (§ 362.)

Experiment 64.—Divide a circle into black and white sectors, as shown in Fig. 170, and attach it to a whirling table (§ 74). Revolve it so rapidly that the colors blend and the disc appears a uniform gray. Darken the room and illuminate the rapidly revolving disc by the electric spark from a Leyden jar. The disc will appear at rest and each sector will appear separate from its neighbors. This shows that the duration of the electric spark is less than the persistence of vision.

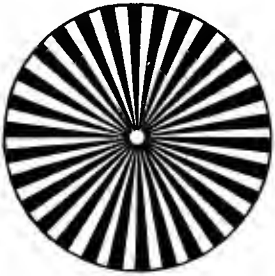


FIG. 170.

FIG. 171.

Experiment 65.—In a dark room, place a piece of loaf sugar in contact with the outside coat of a charged Leyden-jar. Place one knob of the discharger upon the sugar and bring the other near the knob of the jar. When the jar is discharged thus through the sugar, the sugar will glow for some time.

Experiment 66.—The "luminous jar," represented in Fig. 171, is a modified Leyden jar. The outer coat consists chiefly of a layer of varnish sprinkled over with metallic powder. A strip of tin-foil at the bottom affords means of communication with the earth. A similar band at the upper edge of the outer coat is provided with an arm, as shown in the figure. The rod of the jar is curved so as to bring the knob near the projecting arm of the outer coat. The jar is suspended by the curved rod from the prime conductor and its lower strip of tin-foil connected with the earth. When the machine is worked, sparks pass between the knob and the projecting arm. In a dark room, the metallic powder coat will be beautifully illuminated at the passage of each such spark.

FIG. 172.

Experiment 67.—The "luminous pane" is represented in Fig. 172. A continuous tin-foil strip is pasted back and forth upon the surface of a plate of glass. The upper end of this strip is connected with the prime conductor; the lower end with the earth. A series of breaks in this continuous conductor may be made by cutting it across with a sharp pen-knife. When the machine is worked, a small spark will appear at each break thus made. These breaks may be arranged so as to represent a flower, star, arch, word or other design. The sparks are really successive, but they seem to be simultaneous.

Experiment 68.—The "luminous globe" is represented in Fig. 173 and the "luminous tube" in Fig. 174. The first of these consists of a hollow glass globe, on the inner surface of which small discs of tin-foil are placed very near each other. The first disc is in connection with the prime conductor, and the last one with the ground. When the machine is

FIG. 173.

FIG. 174.

worked, bright sparks appear at each break between the discs. The construction and action of the luminous tube are similar. All of these luminous effects are best exhibited in the dark.

Experiment 69.—If two barometer tubes, united at the top, be filled with mercury and inverted over two cups of mercury, as shown in Fig. 175, a Torricellian vacuum will be formed at the bend. When the mercury of one cup is connected with the prime conductor and that of the other with the earth, the upper part of the tube (containing only mercuric and other vapors) is filled with light. The luminosity may be increased by raising the temperature and thus increasing the density of the aëriform conductor. (A true vacuum will not conduct electricity.) The apparatus may be put into the circuit of an induction coil instead of connecting it with the prime conductor and the earth.

FIG. 175.

Experiment 70.—"Geissler's Tubes" are sealed glass tubes containing a highly rarefied vapor or gas. Platinum wires are sealed into the glass at each end, to conduct the electric current to the interior of the tube. The brilliancy and beauty of the light, the great variety of effects, color and fluorescence, are indescribable. They are made in great variety of form and size and filled with rarefied vapors and gases of many kinds. A few of the forms are represented in Fig. 176. They may be used in the dark with an electric machine or an induction coil (§ 459).

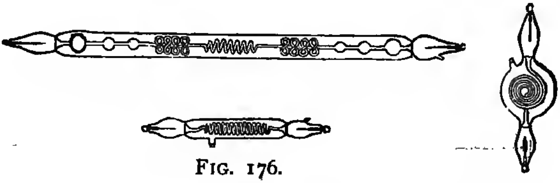


FIG. 176.

Experiment 71.—In "Crookes's Tubes," devised in many forms by Prof. Crookes for his investigations of the phenomena of "radiant matter" (§ 59 *b*), the tension of the contained gas is reduced to about one millionth of an atmosphere, far below that of Geissler's tubes. Under the influence of the electric discharge, matter seems to be radiated from the negative pole in straight lines and in directions perpendicular to the radiating surface.

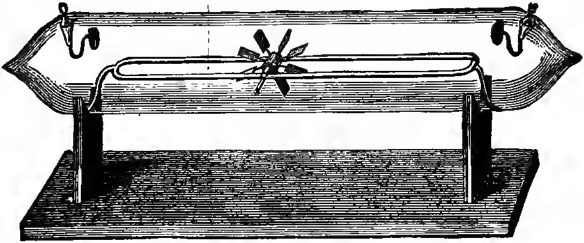


FIG. 177.

(*a*.) One of these tubes, used to show that "radiant matter" may exert mechanical action, is shown in Fig. 177. It consists of a highly exhausted glass tube containing a glass railway. The axle of a small wheel revolves on the rails, the spokes of the wheels carrying mica paddles. Pole pieces are fused in through the glass, as represented. Whichever pole is made negative, "radiant matter" darts

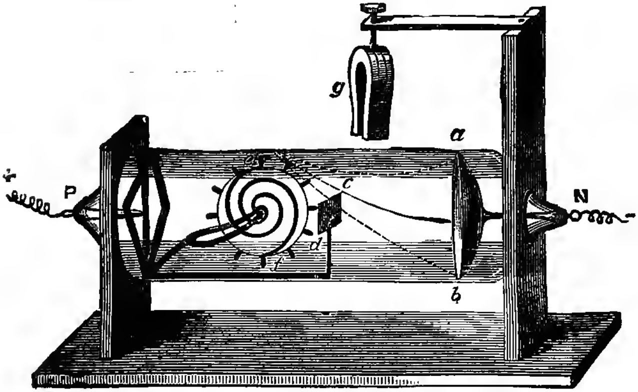


FIG. 178.

from it along the tube, strikes the upper paddles, causing the wheel to roll along the railway. By reversing the poles, the motion of the wheel may be stopped and reversed.

(*b.*) To show that "radiant matter" may be deflected from a straight line, he devised the tube shown in Fig. 178. The negative pole, *a b*, is in the form of a shallow cup. A mica screen, *c*, shields the mica paddle-wheel, *e f*. By holding one pole of the magnet, *g*, over the tube, the matter radiated from *a b* is deflected upward and the wheel caused to revolve like an overshot water-wheel. By holding the other pole of the magnet over the tube, the molecular stream is deflected downward and the wheel caused to revolve as an undershot water-wheel. (See Appendix C.)

372. Relation of Electricity to Energy.—The work necessarily performed in operating an electric machine is not all expended in overcoming inertia and friction. Much of it is employed in producing electric separation. It matters not whether this separation be the separation of two fluids or of something else. *Whatever be the nature of the realities separated, mechanical, kinetic energy is employed in the separation and converted into the potential variety* (§ 159).

An electrified pith ball or a charged Leyden jar is simply an electrostatical reservoir of potential energy. In the discharging of such a body, the passage of the current is accompanied by a loss of potential energy. What becomes of this energy? This leads us to look for effects due to it, to work done by it. Many illustrations of work thus done have been furnished in the experiments just described. In every case of electric attraction or repulsion, we have an evident reconversion of this potential energy into mechanical kinetic energy. We shall soon see that the sound, heat and light accompanying electric discharges are forms of energy due to the conversion of the potential energy of electric separation. We shall see other effects, more or less powerful, when we come to study voltaic and other forms of current electricity.

EXERCISES.

1. (*a.*) If a gold-leaf electroscope be placed within a tin pail which is insulated and electrified, what will be the action of the electroscope? (*b.*) Explain.

2. (*a.*) Why may one obtain a stronger spark from a Leyden jar than from the machine by which it is charged? (*b.*) A Leyden jar standing upon a glass plate cannot be strongly charged. Why?

3. (*a.*) A globe that is polished will remain electrified longer than one that is not polished. Why? (*b.*) Can you devise an appendage to the outer coat of a Leyden jar, so that it may be charged when standing upon a plate of glass?

4. (*a.*) Describe the plate electric machine. (*b.*) Explain its action. (*c.*) Explain the action of the electrophorus.

5. (*a.*) A minute after the discharge of a Leyden jar, a second and feebler spark may generally be obtained. Explain. (*b.*) State two uses of lightning-rods.

6. (*a.*) Having a metal globe positively electrified, how could you with it negatively electrify a dozen globes of equal size without affecting the charge of the first? (*b.*) How could you charge positively one of the dozen without affecting the charge of the first?

7. Can you devise a plan by which a series of Leyden jars, placed upon a glass plate, may be simultaneously charged, the first positively, the second negatively, the third positively, the next negatively and so on?

8. How would you prove that there is no electrification within a closed conductor?

9. At what distance from a small sphere charged with 28 units of electricity must you place a second sphere charged with 56 units that one may repel the other with a force of 32 dynes? *Ans. 7 cm.*

10. If a number of Leyden jars be separately charged in the ordinary way and then connected in series, so that the outer coating of one is connected with the inner coating of the next, will the potential of the battery be changed and in what way?

11. Will the "striking distance" of a battery of Leyden jars in series be less or greater than the striking distance (*i.e.*, the greatest distance at which the discharge by spark will take place through air) of a battery of the same number of similar cells arranged abreast as shown in Fig. 152?

12. In what way may an electric charge be divided into three equal parts?

13. Suppose two similar conductors to be electrified, one with a + charge of 5 units and the other with a − charge of 3 units. They are made to touch each other. When they are separated, what will be the charge of each?

Ans. One unit of + electricity.

14. Why are telegraphic signals through a submerged cable retarded in transmission?

Recapitulation.—To be amplified by the pupil for review.

- ELECTRICITY PRODUCED BY FRICTION.
  - KINDS AND NAMES.
  - ELECTROSTATIC LAWS.
  - ELECTRICAL UNITS AND TESTS.
  - ELECTROSCOPES.
  - CONDUCTION......
    - CONDUCTORS, NON-ELECTRICS.
    - INSULATORS, ELECTRICS.
  - TENSION, POTENTIAL AND CAPACITY.
  - ELECTRIFICATION.
    - BY CONTACT.
    - BY INDUCTION.
      - POLARIZATION.
      - ELECTROPHORUS.
      - ELECTRIC MACHINES.
      - SOURCE OF ENERGY.
  - PROVISIONAL THEORY.
  - DISTRIBUTION OF CHARGE.
    - ON SURFACE.
    - DENSITY.
  - CONDENSERS......
    - DIELECTRICS.
    - INDUCTIVE CAPACITY.
    - LEYDEN JAR.
    - LEYDEN BATTERY.
    - SUBMARINE CABLES.
  - DISCHARGE........
    - DISRUPTIVE.
    - CONVECTIVE.
    - CONDUCTIVE.
  - ATMOSPHERIC E.
    - THUNDER STORMS.
      - LIGHTNING.
      - LIGHTNING-RODS
    - AURORA BOREALIS.
  - RELATION TO ENERGY.

SECTION III.

VOLTAIC AND THERMO-ELECTRICITY.

373. Chemical Action.—All chemical changes are accompanied by electric separation. The substances acted upon may be solid, liquid or aëriform, but the chemical action between liquids and metals gives results the most satisfactory. Electricity thus developed is called *voltaic or galvanic electricity.* Its energy is derived from the potential energy of chemical affinity (§ 7).

374. Current Electricity.—The principal classes of electric currents are as follows:

(1.) *Currents produced by chemical action, i. e., voltaic electricity.*

(2.) *Currents produced by heat, i. e., thermo-electricity.*

(3.) *Currents produced by other electric currents or by magnets, i. e., induced electricity.*

(*a.*) We have seen that, when a body having an electrical charge is properly connected with another of lower potential, there is a transfer of electricity from the former to the latter. This implies that there is an electric current. But this current is only momentary and of little importance in comparison with the currents that we are about to consider. Current electricity may differ from static electricity in quantity, electromotive force, *etc.*, *but not in its nature.*

375. The Voltaic Current.—When a strip of copper and one of zinc are placed in dilute sulphuric acid or in a battery solution like the one already used, the two strips being connected above the acid by a wire conductor, a current of electricity is produced. *The apparatus here described is called a voltaic or galvanic element or cell.*

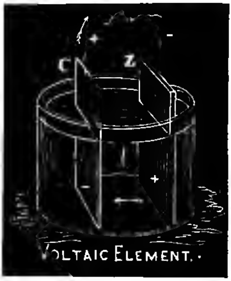


FIG. 179.

(*a*) For voltaic purposes, the sulphuric acid should be diluted by slowly *pouring the acid* into ten or twelve times its bulk of soft water. Do not pour the water into the acid.

376. Whence the Energy of Current?—The energy of the current is due to the potential energy of chemical affinity existing between the acid and the zinc. As the chemical affinity between coal and oxygen develops, in the furnace, a form of kinetic energy that we call heat, so the potential energy of chemical separation between the acid and the zinc develops, in the cell, the two varieties of kinetic energy, heat and electric current. The coal is consumed in the one case; the zinc, in the other.

377. Direction of the Current.—For this production of the electric current, it is necessary that the liquid have a greater action upon one plate than upon the other. The plate that is more vigorously acted upon by the liquid constitutes the generating or positive plate; the other, the collecting or negative plate. This relation of the plates determines the direction of the current. *In the liquid, the current is from the positive to the negative plate; in the wire, the current is from the positive to the negative electrode. In each* *case, the current passes from + to —.* The direction of the current is indicated by arrows in Fig. 179.

When the wires from the two plates are in contact, it is said that the *circuit is closed;* when the plates are not thus in electric connection, it is said that the *circuit is broken.*

378. Electrodes.—It may help the memory to suppose that, in a voltaic cell, two currents, opposite in kind and direction, are simultaneously produced. It will be readily understood, by keeping in mind the direction of these two currents, that, if the circuit be broken, negative electricity will accumulate at the end of the wire attached to the positive plate and positive electricity at the end of the wire attached to the negative plate. *These ends of the wires are then called poles or electrodes. The negative pole is attached to the positive plate and vice versa. The plate or electrode from which the current flows is +; that toward which the current flows is —.* Strips of platinum are often fastened to the ends of the wires; these platinum strips then constitute the electrodes.

379. Resistance.—Every electric circuit offers a resistance to the passage of the current. This resistance will, of course, depend largely upon the materials used for the circuit. (See Appendix K.)

(1.) *With a conducting wire of a given material, the resistance is proportional to the length.* If the resistance of a mile of telegraph wire be 13 ohms, the resistance of 50 miles of such wire will be (13 ohms × 50 =) 650 ohms.

(2.) *With a conducting wire of a given material,* *the resistance is inversely proportional to its sectional area, to the square of its diameter or to its weight per linear unit.* If one conductor be twice the diameter of another made of the same length and material, the sectional area or the weight *per* foot or yard will be ($2^2 =$) four times as great and the resistance of the first will be one-fourth as great as that of the second. If they be made of the same material and length, one weighing twice as much *per* foot as the latter, the resistance of the former will be half as great as that of the latter. (See Appendix I.)

(3.) *The resistance of a conducting wire of given length and thickness depends upon the material of which it is made, i. e., upon the specific resistance of the material.* (See Appendix K, [2].)

(4.) The resistance of a given conductor may vary with its temperature. (See Appendix K, [3].)

(*a.*) Conductivity and resistance are reciprocals, but it is more common to speak of the resistances of conductors than of their conductivities.

380. The Practical Unit of Resistance.—*The practical unit of resistance is called an ohm. A megohm is a million ohms. A microhm is one-millionth of an ohm.* The ohm is the resistance of a column of mercury one square millimeter in section and at the freezing temperature (0° C.). The exact length of this column is to be determined experimentally by an international commission. A recent determination of the value of the ohm (probably the best yet made) gives the mercury column a length of 106.3 *cm.* If the pupil will get, from some dealer in electrical supplies, 40 ft. of No. 24 insulated copper wire (see Appendix I), he will have a very good standard ohm.

(*a.*) A galvanized iron (telegraph) wire, 4 millimeters in diameter and 100 meters long, or a pure copper wire, 1 millimeter in diameter and 48 meters long, has a resistance of about one ohm. An ohm equals 10^9 absolute electro-magnetic units (§ 452). (For the measurement of resistances, see Appendix M, [2 and 3].)

381. Examples.—(*a.*) If the resistance of 130 yd. of copper wire, $\frac{1}{16}$ inch in diameter, be one ohm, what is the resistance of 260 yd. of copper wire, $\frac{1}{32}$ inch in diameter? Since the diameter of the first wire is twice that of the second, the sectional area of the first will be four times that of the second. (Areas of circles are proportional to the squares of their diameters.) Therefore, the resistance of the same length (130 yds.) of the smaller wire will be four times that of the larger wire, or 4 ohms. But the second or smaller wire is twice as long. Therefore, its resistance will be twice ($\frac{260}{130}$) as great, or 8 ohms. *Ans.* 8 ohms.

(*b.*) What is the resistance of 20 yd. of platinum wire, 0.016 inch in diameter, if the resistance of 200 yd. of copper wire, 134 mils in diameter, is 0.34 ohm and the relative resistances of platinum and copper are as 11.3 : 1? (A *mil* is the one-thousandth of an inch. The term is frequently used in descriptions of wire.)

$$0.34 \text{ ohm} \times \frac{20}{200} \times \left(\frac{134}{16}\right)^2 \times \frac{11.3}{1} = 26.95 \text{ ohms.}$$

Ans. 26.95 ohms.

382. Electromotive Force.—Electromotive force (often written *E. M. F.* or simply *E.*) is the mysterious power that causes a transfer of electricity from one point to another. It is somewhat analogous to hydrostatic pressure. Wherever there is difference of potential, there is *E. M. F.* The terms are not synonymous, although, for convenience, *E. M. F.* is often expressed as difference of potential and *vice versa*. The *E. M. F.* of a voltaic cell depends upon the nature of the materials used and not upon the size of the plates or the distance between them.

The unit of electromotive force is called a volt. A microvolt is one-millionth of a volt.

A volt is a little less than the *E. M. F.* of a Daniell cell (§ 394), which measures 1.079 volts.

(*a.*) A volt equals 10^8 absolute electro-magnetic units (§ 452). (For the measurement of *E. M. F.* see Appendix M, [4].)

383. Internal Resistance. — We may imagine that the two plates of a voltaic cell are connected by a liquid prism. The greater the distance between the plates, the longer this prism and the greater its resistance. The larger the plates, the larger the prism and the less its resistance. (See Appendix M, [3].)

When the circuit is closed, hydrogen is set free by the decomposition of the liquid and rises from the surface of the negative plate. Gases are poor conductors. Hence, the hydrogen bubbles that often adhere to the negative plate increase the internal resistance of the cell by lessening the effective surface of the plate (§ 389). This tendency of the hydrogen to adhere to the plate is one of the practical difficulties to be overcome in working a voltaic cell or battery.

384. Fall of Potential.—The existence of a current is evidence of a difference of potential at any two consecutive points of the circuit. It may be well to compare the flow of electricity with the flow of water in horizontal pipes and difference of potential with difference of

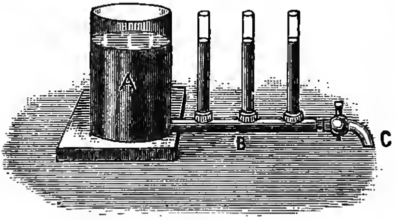


FIG. 180.

hydrostatic pressure. Let Fig. 180 represent a vessel filled with water. The tap at *C* is closed and the water stands at the same level in all of the vertical tubes (§ 234) showing that there is no difference of pressure and, consequently, no liquid flow. Similarly, when there is no difference of potential there is no electric flow. But when the tap at *C* is opened, as represented in Fig. 181, it is noticed that the level in the vertical tubes becomes lower as we pass from *A* toward *C*. The height of water in each vertical tube indicates the pressure at that part of the tube, *B*. This difference in hydrostatic pressure produces a flow of water. In much the same way, if the electric potential of a voltaic circuit be measured at different points, it will be found to decrease from the + pole to the – pole. If the circuit be a wire of uniform size and material, the resistance offered by it will be uniform and the potential will fall uniformly. If, however, the circuit be made to have a varying resistance in different parts, the potential will fall most rapidly along the parts of greatest resistance. For the whole or any part of the circuit, the fall of potential will be proportional to the resistance.

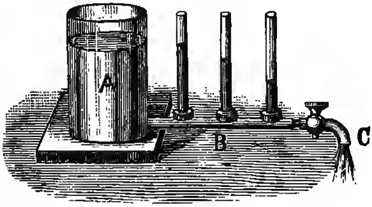


FIG. 181

(*a.*) A number of hydraulic motors may be worked "in series" upon a given water pipe, the outflow of the first being the supply of the second. The work done in any motor may be determined from the quantity of water flowing through the pipe or motor per second and *the difference* between the supply pressure and the back pressure at the motor. There will be a fall of pressure between the two sides of the motor at work. The more work the motor has to do, the more *resistance* it will offer to the flow of water and the greater the fall of pressure. Similarly, a number of telegraphic instruments or electric lamps may be placed in series upon an electric circuit. The work done in each instrument or lamp will depend upon the current strength and the difference of potential between the two terminals of the instrument or lamp. There will be a fall of a certain number of volts between the two terminals, depending upon the intervening resistance.

385. The Ampere.—The strength of current or its rate of flow (often called its intensity) will depend upon electromotive force and resistance, increasing with the former and decreasing with the latter. *The unit of current is called an ampere. One-thousandth of an ampere is called a milli-ampere.* At any given instant, the current is the same at every part of the circuit.

(*a.*) The telegraphic currents commonly used on main lines vary from 5 to 15 milli-amperes. The currents commonly used in electric arc lamps vary from 7 to 20 amperes.

(*b.*) The strength of a current may be measured by its heating effect (§ 471) or by the products of electrolysis, as in the case of the water voltameter (§ 410). But currents are generally measured by instruments like the galvanometer (§ 418), or by their electro-magnetic effects. An instrument so used is called an *ammeter* (abbreviated from ampere-meter). An ampere equals 0.1 or 10^{-1} of an absolute electro-magnetic unit (§ 452).

386. Ohm's Law.—*The strength of current varies directly as the E. M. F. and inversely as the resistance.* This resistance is the total resistance of the circuit, including the internal resistance of the cells or dynamo and the resistance of the external circuit.

$$\frac{Volts}{Ohms} = Amperes, \text{ or } C = \frac{E}{R}. \therefore\ E = C \times R;\ R = \frac{E}{C}.$$

Standards for strength of current have not yet been made.

(*a.*) Ohm's great service (A. D., 1827) to electrical science consisted largely in the introduction of the accurate ideas, electromotive force, current strength and resistance. "Before his time, the quantitative circumstances of the electric current had been indicated in a very vague way by the use of the terms 'intensity' and 'quantity,' to which no accurately defined meaning was attached."

(*b.*) If we have a difference of potential that secures an E. M. F. of 18 volts, and if the total resistance of the circuit be 3 ohms, the strength of the current will be 6 amperes. 18 ÷ 3 = 6. The analogy of flowing water will again help us. The rate at which the water is delivered will depend upon, not only the head or pressure (corresponding to E. M. F.), but also upon the resistance it meets with in flowing. If the pipe be small and crooked or if it be choked with sand or sawdust, the water will flow in a small stream even though the pressure be great.

Experiment 72.—Make four coils or spools of insulated wire as follows: (See Appendix I.)

No. 1, of 100 feet of No. 16 gauge, copper.
No. 2, of 100 " " 30 " "
No. 3, of 50 " " 30 " "
No. 4, of 50 " " 30 " german silver.

Place the wire of the first spool and a galvanometer (§ 418) in the circuit of one cell and note the number of degrees of deflection of the galvanometer needle. Put the second spool in place of the first. The smaller deflection shows that (other things being equal) the No. 16 wire transmits more current than the No. 30. Why? Then add the third spool to the circuit. The still smaller deflection shows that (other things being equal) a long wire transmits less current than a shorter one. Why? Remove the second spool from the circuit and note the deflection of the galvanometer. Put the fourth spool in place of the third. The diminished deflection shows that (other things being equal) a german silver wire transmits less current than a copper wire. Why? With any one of the spools in the circuit, compare the galvanometer deflections produced by a Bunsen cell and by a gravity cell and notice that the former gives the stronger current.

Note.—These experiments give *very crude results* but, such as they are, they fairly represent the measurements that prevailed until recently. More accurate measurements with numerical representations of the results are now demanded. The rapid advances of electrical science within the last few decades have been very largely due to the adoption of definite units and accurate determinations. (See Appendix M.)

387. The Coulomb.—*The unit of quantity is called the coulomb. It is the quantity of electricity given by a one ampere current in one second.* A ten ampere current will give thirty coulombs in three seconds.

(*a.*) The word "quantity" was formerly used in the sense in which the word "intensity" was used in § 385, while the latter word was used as if it depended upon E. M. F. alone. But quantity of electricity, clearly, depends upon the strength of the current *and the time that the current flows.* A coulomb equals 0.1 or 10^{-1} of an absolute electro-magnetic unit of quantity (§ 452).

EXERCISES.

1. What length of No. 10 pure copper wire (B. & S.) will have a resistance of 1 ohm? (See Appendix I.) *Ans.* 961.54 ft.

2. A given battery has an E. M. F. of 12 volts. The internal resistance is 8 ohms. The resistance of the external circuit is 4 ohms. What is the strength of the current?

3. The 4 cells of a given battery are connected so that the total E. M. F. is 4 volts and the internal resistance is 20 ohms. The external circuit has a resistance of 20 ohms. What is the strength of the current? *Ans.* 0.1 ampere.

4. What length of copper wire 4 *mm.* in diameter will have the same resistance as 12 yd. of copper wire 1 *mm.* in diameter? *Ans.* 192 yd.

5. The 4 cells of a given battery are connected so as to give an E. M. F. of 2 volts and to have a total internal resistance of 10 ohms. The external circuit is a stout copper wire with a resistance so small that it may be ignored. What is the current strength?

6. The same battery is used with a telegraphic sounder in the circuit. This instrument has a resistance of 5 ohms. What is the current strength? *Ans.* 133 milli-amperes.

7. The resistance of 47 ft. of copper wire, 22 mils in diameter being 1 ohm, find the resistance of 200 yd. of copper wire 134 mils in diameter *Ans.* 0.34 ohm.

☞ If you do not know what a mil is, consult the Index.

8. A battery has a current of 2 amperes flowing through a total resistance of 9 ohms. What is the E. M. F.?

9. The E. M. F. of a battery is 10 volts. The current is 1 ampere. The external resistance is 5 ohms. What is the internal resistance of the battery? *Ans.* 5 ohms.

10. The potential of a current falls 45 volts between the two terminals of an incandescence lamp. The current measures 1.25 amperes. What is the resistance of the lamp? *Ans.* 36 ohms.

☞ If you do not know what an incandescence lamp is, consult the Index.

388. Amalgamating the Zinc.—Ordinary commercial zinc is far from being pure. The chemically pure metal is expensive. When impure zinc is used, small closed circuits are formed between the particles of foreign matter and the particles of zinc. This *local action*, which takes place even when the circuit of the cell or battery is broken, rapidly destroys the zinc plate and contributes nothing to the general current. This waste, which would not occur if pure zinc were used, is prevented by frequently amalgamating the zinc. This is done by cleaning the plate in dilute acid and then rubbing it with mercury.

(*a.*) The method of amalgamating battery zincs practised by the author is as follows: In a glass vessel placed in hot water, dissolve 15 *cu. cm.* of mercury in a mixture of 170 *cu. cm.* of strong nitric acid and 625 *cu. cm.* of hydrochloric (muriatic) acid. When the mercury is dissolved, add 830 *cu. cm.* of hydrochloric acid. When the liquid has cooled, immerse the battery zinc in it for a few minutes, remove and rinse thoroughly with water. The liquid may be used over and over until the mercury is exhausted. The quantity here mentioned will suffice for 200 ordinary zincs or more. Keep the liquid, when not in use, in a glass-stoppered bottle.

389. Polarization.—It was stated in § 383 that the accumulation of hydrogen bubbles at the negative plate increases the internal resistance of the cell. But the hydrogen affects the current in another way. It acts like a positive plate (being almost as oxidizable as the zinc) and sets up an opposing electromotive force that tends to set a current in the opposite direction. *A cell or battery in this condition is said to be polarized.* Sometimes, as a result of polarization, the strength of the current falls off very greatly within a few minutes after closing the circuit. (See § 414.)

390. Varieties of Voltaic Cells.—All voltaic cells belong to one of two classes:

(1.) *Those using only one liquid.*

(2.) *Those using two liquids.*

All of the earlier batteries were composed of one-liquid cells.

Note.—When dilute sulphuric acid is mentioned in connection with cells and batteries, it may be understood that one volume of acid to ten or twelve volumes of water is meant.

391. Smee's Cell.—A Smee's cell is represented by Fig. 182. It consists of a platinized silver plate placed between two zinc plates hung in dilute sulphuric acid. The hydrogen bubbles accumulate at the points of the rough platinum surface and are more quickly carried up to the surface of the liquid and thus gotten rid of. The cell has an *available* electromotive force of about 0.47 volt.

FIG. 182.

392. Potassium Di-chromate Cell.—The potassium di-chromate cell has a zinc plate hung between two carbon plates. A solution of potassium di-chromate (bi-chromate of potash) in dilute sulphuric acid is the liquid used. The hydrogen is given an opportunity for chemical union as fast as it is liberated. The E. M. F. of this cell is great to start with (from 1.8 to 2.3 volts), but it falls very quickly when the external resistance is small. It quickly recovers and may be used with advantage where powerful currents of short duration are often wanted. It is the only single liquid cell that is free from polarization.

(*a.*) The bottle form of this cell, represented in Fig. 183, is the most convenient for the laboratory or lecture table. By means of the sliding rod, the zinc plate may be raised out of the solution when not in use. Thus adjusted, the cell may remain for months without any action, if desired, and be ready at a moment's notice.

FIG. 183.

(*b.*) One of the best proportions for the solution is as follows: One gallon of water, one pound of potassium di-chromate and from a half pint to a pint of sulphuric acid, according to the energy of action desired. A small quantity of nitric acid added to the solution increases the constancy of the battery by oxidizing the nascent hydrogen and thus forming water.

(*c.*) The following recipe is good: Pour 167 *cu. cm.* of sulphuric acid into 500 *cu. cm.* of water and let the mixture cool. Dissolve 115 *g.* of potassium di-chromate in 335 *cu. cm.* of boiling water and pour, while hot, into the dilute acid. When cool, it is ready for use.

393. The Leclanche Cell.—This cell, shown in Fig. 184, contains a zinc plate or rod and a porous, earthenware cup containing the carbon plate. The space between the carbon plate and the cup is filled with fragments of carbon and powdered peroxide of manganese. This cup replaces the second metal plate. The liquid used is a solution of ammonium chloride (sal-ammoniac) in water. This cell is tolerably constant if it be not used to produce very strong currents, but its great merit is that *it is very permanent.* It will keep in good condition for months with very little attention, furnishing a current *for a short time* whenever wanted.

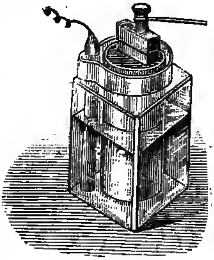


FIG. 184.

It is much used for working telephones, electric bells (Fig. 232) and clocks, railway signals, *etc.* The manganese oxide prevents polarization by destroying the hydrogen bubbles. If the cell be used continuously for some time, its power weakens owing to the accumulation of hydrogen, but if left to itself it gradually recovers as the hydrogen is oxidized. Sometimes the manganese oxide is applied to the face of the carbon and the porous cup dispensed with. This cell has an E. M. F. of about 1.5 volts. *It should be left on open circuit when not in use.*

394. Daniell's Cell.—This cell consists of a copper plate immersed in a saturated solution of copper sulphate (blue vitriol) and a zinc plate immersed in dilute sulphuric acid or a solution of zinc sulphate (white vitriol). The two liquids are separated; usually one liquid is contained in a porous cup placed in the other liquid. Crystals of copper sulphate are placed in the solution of copper sulphate to keep the latter saturated. Such a cell will furnish a nearly constant current, with an E. M. F. of 1.079 volts and keep in order for a long time. *It should be kept on closed circuit when not in use.* The hydrogen passes through the porous cell and acts upon the solution of copper sulphate. Copper, instead of hydrogen, is deposited upon the copper plate. Polarization is thus avoided. If an incrustation forms near the zinc plate, remove some of the solution of zinc sulphate and dilute what remains with water.

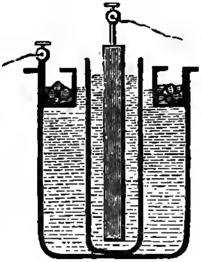


FIG. 185.

(*a.*) In Fig. 186, the copper plate is represented as a cleft cylinder within the porous cup, the crystals being piled up around it. It is common to interchange the plates, the zinc being in dilute sulphuric acid within the porous cup, and the copper plate in the saturated acid outside the porous cup. Sometimes the outer vessel itself is made of copper instead of glass and serves as the copper plate as is shown in Fig. 185.

FIG. 186.

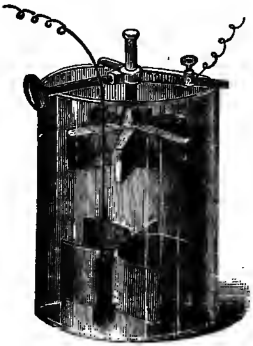


FIG. 187.

395 The Gravity Cell.—This is a modification of the Daniell's cell, no porous cup being used. The copper plate is placed at the bottom of the cell and the zinc plate near the top. Crystals of copper sulphate are piled upon the copper plate and covered with a saturated solution of copper sulphate. Water or, preferably, a weak solution of zinc sulphate rests upon the blue solution below and covers the zinc plate. The two solutions are of different specific gravities and remain clearly separated if the cell be kept on closed circuit when not in use. (Fig. 187.) This cell is very largely used in working telegraph lines. It is sometimes called the Callaud cell.

396. Grove's Cell.—The outer vessel of a Grove's cell contains dilute sulphuric acid. In this is placed a hollow cylinder of zinc. Within the zinc cylinder is placed a porous cup containing strong nitric acid. The negative plate is a strip of platinum placed in the nitric acid. The hydrogen passes through the porous cup and reduces the nitric acid to nitrogen peroxide, which escapes as brownish-red fumes. These nitrogen fumes are disagreeable and injurious; it is well, therefore, to place the battery in a ventilating chamber or outside the experimenting room. The E. M. F. of the Grove cell, under favorable conditions, is nearly two volts, while its internal resistance is small, being about one-fifth that of a Daniell's cell. It is much used for working induction coils (consult the Index), for generating the electric light, *etc.* It is, however, troublesome to fit up and should have its liquids renewed every day that it is used. Fig. 189 represents a Grove's battery with cells *joined in series.*

397. Bunsen's Cell.—Bunsen's cell (Fig. 188) differs from Grove's in the use of carbon instead of expensive platinum for the negative plate, thus reducing the cost. The plates are made larger than for Grove's battery. Its E. M. F. is about the same as that of the Grove cell but its internal resistance is greater. Fig. 190 represents a battery of Bunsen's cells *joined in multiple arc.*

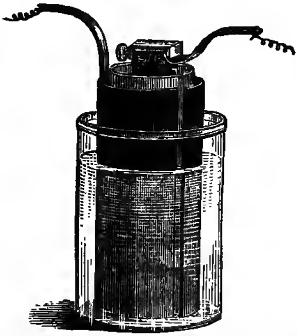


FIG. 188.

Note.—There are scores of different kinds of cells in the market competing for favor. Those here described are among the ones most commonly used.

398. A Voltaic Battery.—*A number of similar voltaic elements connected in such a manner that the current has the same direction in all, constitutes a voltaic battery.* The usual method is to connect the positive plate of one element with the negative plate of the next, as shown in Fig. 189. When thus connected, they are said to be coupled "tandem" or "in series." Sometimes all of the positive plates are connected by a wire and all of the negative plates by another wire. The cells are then said to be joined "parallel," "abreast" or "in multiple arc." (See Fig. 190.)

(*a.*) When two or more cells are joined together, the points of contact should be as large as is convenient and kept perfectly clean. The connecting wire should be of good size and, for the sake of pliability, a part of it may well be given a spiral form by winding it upon a pencil or other small rod.

399. Batteries of High Internal Resistance.—Each kind of galvanic cell has an internal resistance, as explained in § 383. A battery of cells joined in series is called a "battery of high internal resistance." (Fig. 189). This method of joining the cells increases

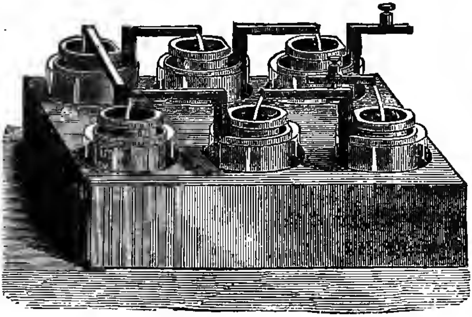


FIG. 189.

the length of the liquid conductor through which the current passes.

(*a.*) In a battery of cells joined in series, the E. M. F. and the internal resistance are those of a single cell multiplied by the number of cells. For a circuit of great external resistance, a battery of high internal resistance is needed.

400. Batteries of Low Internal Resistance.—A battery of cells joined parallel is called a "battery of low internal resistance." (Fig. 190.) This method of joining the cells does not increase the length of the liquid conductor traversed by the current but is equivalent to increasing its diameter or sectional area.

(*a.*) In a battery of cells joined parallel, the E. M. F. is that of a single cell, but the internal resistance is that of a single cell divided by the number of cells. For a circuit of small external resistance, large cells, or several cells joined parallel, are preferable.

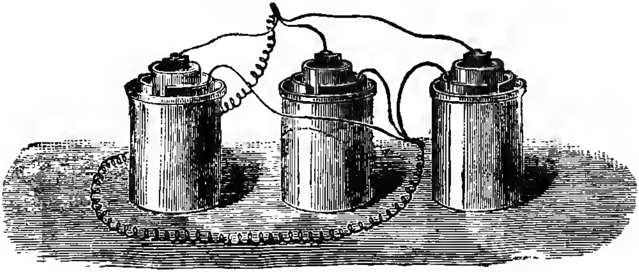


FIG. 19C.

(*b.*) A battery of high internal resistance was formerly called an *intensity* battery, while a battery of low internal resistance was called a *quantity* battery.

401. Requisites of a Good Battery.—The following conditions should be met by a battery:

(1.) Its electromotive force should be high and constant.

(2.) Its internal resistance should be small.

(3.) It should give a constant current and, therefore, must be free from polarization; it should not be liable to rapid exhaustion, requiring frequent renewal of the acid.

(4.) It should be perfectly quiescent when the circuit is open.

(5.) It should be cheap and of durable materials.

(6.) It should be easily manageable and, if possible, should not emit corrosive fumes.

As no single battery fulfills all these conditions, some batteries are better for one purpose and some for another. Thus, for telegraphing through a long line of wire a considerable internal resistance in the battery is no great disadvantage; while, for producing an electric light, much internal resistance is absolutely fatal.

402. The Best Arrangement of Cells.—The best method of coupling cells in any given case depends on the work to be done by the battery. *The maximum effect is attained when the resistance of the external circuit is made equal to the internal resistance of the battery.*

(*a.*) For example, suppose that in a given battery of eight cells:

(1.) Each cell has an E. M. F. of two volts.

(2.) Each cell has the very high internal resistance of eight ohms.

(3.) The battery is to work through a wire that has a resistance of sixteen ohms.

(*b.*) First, couple the cells parallel. The E. M. F. of the battery is that of a single cell, 2 volts. The internal resistance is 8 ohms $\div 8 = 1$ ohm. Adding the external resistance, we have a total resistance of 17 ohms. (See § 386.)

$$C = \frac{E}{R} = \frac{2}{1 + 16} = 0.1176+.$$

This arrangement gives a current of 0.1176+ amperes.

(*c.*) Next, couple the cells in series. The E. M. F. of the battery is 8 times 2 volts, or 16 volts. The internal resistance is 8 times 8 ohms or 64 ohms. Adding the external resistance, we have a total resistance of 80 ohms.

$$C = \frac{E}{R} = \frac{16}{64 + 16} = 0.2.$$

This arrangement gives a current of 0.2 amperes.

(*d.*) Finally, join the cells in two rows (each row being a series of four cells) and join the rows parallel. The E. M. F. of the battery will be 4 times 2 volts or 8 volts. The internal resistance will be 4 times 8 ohms or 32 ohms for each row, but only half that, or 16 ohms, for the whole battery. Adding the external resistance, we have a total resistance of 32 ohms.

$$C = \frac{E}{R} = \frac{8}{16 + 16} = 0.25.$$

This arrangement, in which the internal and the external resistances are equal, gives a current of 0.25 amperes, the greatest possible under the given conditions.

(*e.*) A similar application of Ohm's law shows that *when the external resistance is large, there is little gain from joining cells parallel, and that when the external resistance is very small, there is little gain in joining cells in series.*

EXERCISES.

1. Given ten cells, each with an electromotive force of 1 volt and an internal resistance of 5 ohms. What is the current (in amperes) of a single cell, the external resistance being 0.001 ohm?

Ans. 0.19996+ amperes.

2. The ten cells above mentioned are joined abreast. The external resistance is 0.001 ohm. What is the current of the battery?

Ans. 1.996+ amperes.

3. The ten cells above mentioned are joined tandem, the external resistance remaining the same. What is the current of the battery?

Ans. 0.19999+ amperes.

4. What is the current given by one of the above mentioned cells when the external circuit has a resistance of 1000 ohms?

Ans. 0.00099502 amperes.

5. When the ten cells are joined abreast with an external resistance of 1000 ohms, what is the current of the battery?

Ans. 0.0009995 amperes.

6. When the ten cells are joined in series with an external resistance of 1000 ohms, what is the current of the battery?

Ans. 0.00992 ampères.

Note.—Compare the results in Exercises 1, 2 and 3, where we have a small external resistance. Then compare the results in Exercises 4, 5 and 6, where we have a high external resistance.

7. Why are cells arranged tandem for use on a long telegraphic line?

8. What is the resistance of 2 miles of No. 6 electric light wire (copper of ordinary commercial quality)? (See Appendix I.)

Ans. 4.54 ohms.

9. A Brush dynamo, No. 8, will operate 65 arc lamps on a short circuit. Each lamp has a resistance of about 4.52 ohms. If the lamps be put on a 10 mile circuit of No. 6 copper wire, how many lamps should be "cut out" of the circuit, the dynamo running at the same speed and the current strength remaining the same?

Ans. 5 lamps.

10. Show, by a diagram, how a battery of three cells should be arranged when the internal resistance is the principal one to be overcome.

11. What is the resistance of a mile of ordinary No. 6 iron telegraph wire? (See Appendix K, [2].) *Ans.* 12.9 ohms.

12. Show that the conductivity of water is increased more than 50 times by adding half its volume of sulphuric acid. (See Appendix K, [2].)

13. How much is the conductivity of water increased by adding $\frac{1}{11}$ its volume of sulphuric acid? *Ans.* About 22 times.

403. Long and Short Coil Instruments.—A "long coil" galvanometer, or a "long coil" electro-magnet, or an instrument of any kind in which the conductor is a long, thin wire of high resistance, should not be employed on circuits the other resistances of which are small. Conversely, on circuits of great length, or where there is a high resistance, "short coil" instruments are of little service for, though they add little to the resistances, their few turns of wire are not enough with the small currents that circulate in high-resistance circuits; "long coil" instruments are here appropriate, as they multiply the effects of the currents by their many turns. Their resistance, though perhaps large, is not a serious addition to the existing resistances of the circuit.

404. Divided Circuits and Shunts.—The case of several wires forming a multiple arc often occurs in practice. In such cases, *the current flowing in each branch is inversely proportional to the resistance of that branch.* Either of two such branches is called a shunt. Evidently, the joint resistance of all the branches is less than the resistance of any one of them.

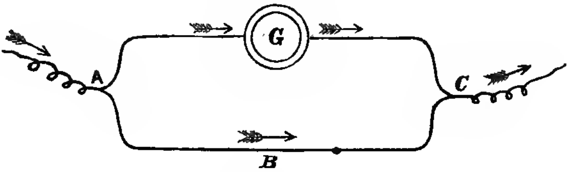


FIG. 191.

(*a.*) A current flowing along a conductor divides at A, part going through a galvanometer or electro-magnet at G and the rest going through the branch, B. The currents unite at C. If the conductor, AGC, has a resistance of 99 ohms and the conductor, ABC, has a resistance of 1 ohm, 1 per cent. of the total current will go through G and 99 per cent. will go by way of B.

(*b.*) If we have two wires, the separate resistances of which are respectively 28 ohms and 24 ohms, placed abreast in a circuit, find their joint resistance. The joint conductivity will be the sum of the separate conductivities and conductivity is the reciprocal of resistance. Call the joint resistance R.

$$\frac{1}{R} = \frac{1}{28} + \frac{1}{24} = \frac{24}{672} + \frac{28}{672} = \frac{52}{672}. \quad \therefore R = \frac{672}{52} = 12.92.$$

The joint resistance will be 12.92 ohms.

(*c.*) The joint resistance of the two branches of a divided conductor is equal to the product of the separate resistances divided by their sum. If there are more than two branches, the method employed above may be used.

(*d.*) It is often necessary to use a sensitive galvanometer or other instrument with a current so strong that the current would give indications too large for accurate measurement or even ruin the instrument. Under such circumstances, the greater part of the current may be shunted around the galvanometer. The resistance of the shunt having a known ratio to that of the galvanometer and its branch, the total current strength may be computed from the strength of the current flowing through the instrument. Shunt circuits may be found in almost all arc lamps.

405. Mechanical Effects of the Electric Current.—The piercing of the glass walls of an overcharged Leyden jar affords a good, though expensive, illustration of the mechanical effects of electricity. Trees and telegraph poles shattered by lightning are not unfamiliar. But, by far, more important for our consideration are the mechanical effects produced by voltaic or dynamic electricity and, especially, *the numerical relation between the electricity used and the work done.* This subject will be considered in Section VI. of this chapter.

Experiment 73.—Through a long, thin platinum wire, send a current that will heat it to dull redness. Apply a piece of ice to the wire and notice that the rest of the wire glows more brightly than it did before. Then heat a part of the wire with the flame of a spirit lamp and notice that the rest of the wire glows less brightly than before. In the first case, the current is strengthened by the increased conductivity of the cooled part; in the second case, the current is decreased by the increased resistance of the part heated by the lamp.

Experiment 74.—When two curved metal surfaces rest upon each other, a current passing from one to the other encounters considerable resistance at the small area of contact. The heat consequently developed causes the parts in the neighborhood to expand very quickly when the contact is made. This often gives rise to rapid vibratory movements in the conductors. *Gore's railway* consists of two concentric copper hoops, whose edges are worked very truly into a horizontal plane. A light copper ball is plsced on the rails thus formed. One rail is connected with the + pole of a battery of two or three Grove cells and the other rail with the — pole. The ball is then set rolling around the track. If the ball be true and the track well leveled, the energy supplied by the swelling (expansion) at the continually changing point of contact is sufficient to keep up the motion. The ball will roll round and round, giving a crackling sound as it goes.

Experiment 75.—From the poles of a potassium di-chromate battery, lead two stout copper wires and connect their free ends by two or three inches of *very fine iron or platinum wire.* Coil the iron wire around a lead pencil and thrust a small quantity of gun-cotton into the loop thus formed. Plunge the zinc plate of the battery into the liquid and the iron wire will be heated enough to explode the gun-cotton; it may be heated to redness or even to fusion.

406. Thermal Effects of the Electric Current.—Whenever an electric current flows through a conductor, *part of the electric energy is changed into heat energy. The amount of electricity thus changed into heat will depend upon the amount of resistance offered by the conductor.* In the last experiment, the stout copper wires were good conductors, offered but little resistance and converted but little of the electrical energy into heat energy. The change of material from copper to iron increased that resistance. This increased resistance was again increased by reducing the size of the conductor. For this double reason, the *fine wire* offered so much resistance that a considerable of the current energy was transformed into heat. *Resistance in an electric circuit always produces heat at the expense of the electric current.* Thus, electricity is often used in firing mines in military operations and in blasting. All known metals have been melted in this way, while carbon rods have been heated by a battery of 600 Bunsen's elements until they softened enough for welding. By means of a Leyden jar battery and a universal discharger, remarkable thermal effects may be obtained. Houses are sometimes set on fire by lightning. The numerical relations between electricity and heat are considered in Section VI. of this chapter.

407. Luminous Effects of the Electric Current.—The electric spark, the glow seen when electricity escapes from a pointed conductor in the dark and the various forms of lightning are some of the now familiar luminous effects of electricity. Whenever an electric circuit is closed or broken, there is a spark at the point of contact, due to the heating of a part of the conductor to incandescence. We have seen luminous effects produced by winding the wire from one plate of a voltaic cell round one end of a file and drawing the other electrode along the side of the file, thus rapidly closing and breaking the circuit. If the iron wire used in the last experiment was heated sufficiently, it also gave a luminous effect and illustrated the fundamental principle of the incandescence electric lamp (§ 466).

(*a.*) The most important luminous effects of electricity will be considered in connection with dynamo-electric machines (§ 465). It will be noticed that all of these are secondary thermal effects.

408. Galvani's Experiment.—In 1786, Galvani, a physician of Bologna, noticed convulsive kicks in a frog's legs when acted upon by an electric current. A frog was killed and the hind limbs cut away and skinned, the crural nerves and their attachments to the lumbar vertebræ remaining. Two dissimilar metals were held in contact and their free ends brought into contact with nerve and muscle respectively, as shown in Fig. 192. Convulsive muscular contractions brought the legs into a position similar to

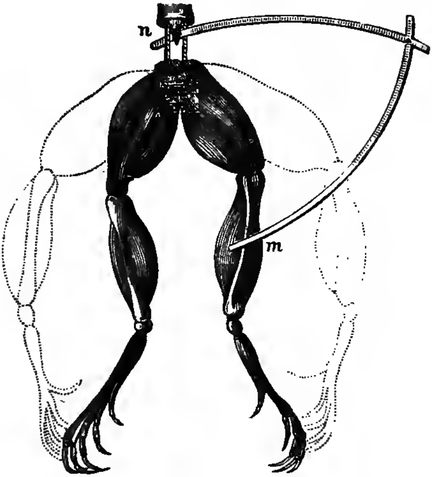


FIG. 192.

that represented by the dotted lines in the figure. A frog's legs thus prepared make a very sensitive galvanoscope. It is said that they show even the very feeble induction currents of the telephone, though the best galvanometers barely detect them.

409. Physiological Effects of the Electric Current.—An electric current may produce muscular convulsions in a recently killed animal. Experiments with the Leyden jar and the induction coil show that similar effects may be produced upon the living animal. The "electric shock," which is physiological in its nature, is familiar to most persons. The sensation thus produced cannot be described, forgotten or produced by any other agency.

Electricity is largely used as an agent for the cure of disease; experiments of this kind may do injury and would better be left to the educated physician. The discharge of a large battery may be fatal and a number of persons have lost their lives within the last few years by coming, accidentally or otherwise, into the circuit of a dynamo-electric machine. Interrupted and alternating currents are more serious in their physiological effects than continuous currents.

(*a*.) If the members of a class form a chain by joining hands, the first member holding a feebly-charged Leyden jar by its outer coat and the last member touching the knob, a simultaneous shock will be felt by each person in the chain. A similar experiment may be made with a Ruhmkorff coil. A single Leyden jar has been discharged through a regiment of 1500 men, each soldier receiving a shock. Dr. Priestley killed a rat with a battery of seven feet of coated surface, and a cat with a battery of forty feet of coated surface.

Experiment 76.—Into a bent tube (known to dealers in chemical glassware as a U tube), put a solution of any neutral salt, *e. g.*, sodium sulphate. Color the contents of the tube with the solution from purple cabbage. In the arms of the tube, place the platinum electrodes of a battery, as shown in Fig. 193. Close the circuit and presently the liquid at the + electrode will be colored red and that at the — electrode, green. If, instead of coloring the solution, a strip of blue litmus paper be hung near the + electrode it will be reddened, while a strip of reddened litmus paper hung near the — electrode will be colored blue. *These changes of color are chemical tests;* the appearance of the green or blue denotes the presence of an alkali (caustic soda in this case), while the appearance of the red denotes the presence of an acid.

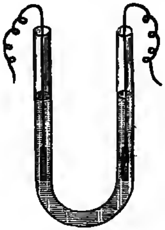


FIG. 193.

Experiment 77.—Melt some tin and pour the melted metal slowly into water. Dissolve some of this granulated tin in hot hydrochloric acid and add a little water. Into this bath of a dilute solution of tin chloride, introduce two platinum electrodes from a battery of a few cells. A remarkable growth of tin crystals will shoot out from the — electrode and spread towards the +, bearing a strong resemblance to vegetable growth. Hence, it is called the "tin tree." Repeat the experiment with solutions of lead acetate ("sugar of lead") and of silver nitrate.

410. Chemical Effects of the Electric Current.—The electric spark may be made to produce chemical combination or chemical decomposition. Ammonia (NH_3), or carbon-dioxide (CO_2), may be decomposed by passing a series of sparks through it. A mixture of oxygen and hydrogen may be caused to enter into chemical union by the electric spark, the product of the union being water. (See *Chemistry*, Exp. 53.) Many chemical compounds may be decomposed by passing the current through them. The compound must be in the liquid condition, either by solution or by fusion. Substances that are thus decomposed are called *electrolytes;* the process is called *elec-*

trolysis; the compound is said to be *electrolyzed.* The electrolysis of acidulated water is easily accomplished with a current from three or four Grove's or Bunsen's cells. The water is decomposed into oxygen and hydrogen. The apparatus, shown in Fig. 194, may be called a *water-voltameter.*

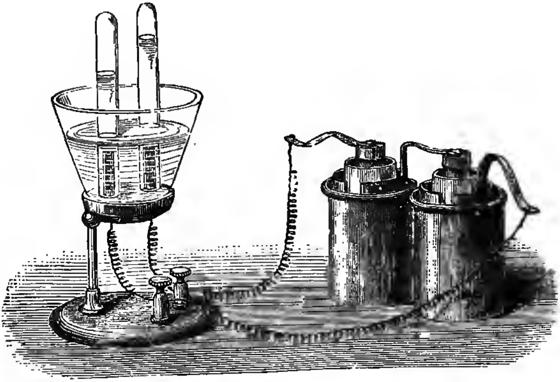


FIG. 194.

(*a.*) The apparatus consists of a vessel containing water (to which a little acid has been added to increase its conductivity) in which are immersed two platinum strips that constitute the two electrodes of a battery. When the circuit is closed, bubbles of oxygen escape from the positive electrode and bubbles of hydrogen from the negative. The gases may be collected separately by inverting, over the electrodes, tubes filled with water, as shown in the figure. The volume of hydrogen thus collected will be about twice as great as that of the oxygen.

(*b.*) A water-voltameter may be made by cutting off the bottom of a wide-mouthed glass bottle (*Chemistry, App.* 4, *h.*) and passing two insulated wires, varnished and terminating in platinum strips, through a cork that closes the mouth of the inverted bottle. Two test tubes will complete the instrument. When a sufficient quantity of the gases has been collected, they may be tested; the hydrogen, by bringing a lighted match to the mouth of the test tube, whereupon the hydrogen will burn; the oxygen, by thrusting a splinter with a glowing spark into the test tube, whereupon the splinter will kindle into a flame.

(*c.*) Each coulomb of electricity liberates 0.1176 *cu. cm.* of hydrogen and 0.0588 *cu. cm.* of oxygen, or a total of 0.1764 *cu. cm.* of the mixed gases. The electrolysis of 9 *g.* of water requires 95,050 coulombs.

411. Ions.—The products of electrolysis, like the oxygen and hydrogen, are called *ions;* the one that goes to the + electrode (or anode) is called the *anion;* the one that goes to the — electrode (kathode or cathode) is called the *kathion* or *cathion.*

(*a.*) The amount of chemical action *in a cell* is proportional to the strength of current while it passes. One coulomb of electricity, in passing through a cell, liberates 0.0000105 gram of hydrogen and dissolves 0.00034125 gram of zinc.

(*b.*) One coulomb will cause the deposition of 0.0003307 gram of copper. To deposit 1 gram of copper requires 3024 coulombs. This principle has been used in the Edison meter for electric lighting purposes, a certain proportion of the current being shunted through a "copper voltameter" or bath of copper sulphate solution, as described in the next experiment.

Experiment 78.—From the + pole of a voltaic battery or dynamo-electric machine, suspend a plate of copper; from the — pole,

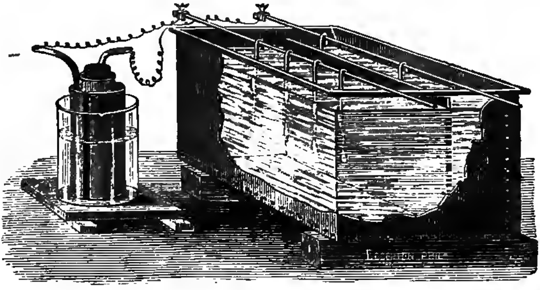


FIG. 195.

suspend a silver coin. Place the copper and silver electrodes in a strong solution of copper sulphate (blue vitriol). When the circuit is closed, the salt of copper is electrolyzed, the copper from the salt being deposited upon the silver coin and the sulphuric acid going to the copper or + electrode. The silver is thus electro-plated with copper. (Fig. 195.)

412. Electro-Metallurgy. — The many applications of this process of depositing a metallic coat on a body prepared for its reception, constitute the important art of electro-metallurgy. If, with the apparatus used in the last experiment, a solution of some silver salt be used instead of the copper sulphate solution and the direction of the current be reversed, silver will be deposited upon the copper plate, which will thus be *silver-plated.* If the positive electrode be a plate of gold and the bath a solution of some salt of gold (cyanide of gold dissolved in a solution of cyanide of potassium), gold will be deposited upon the copper of the negative electrode, which will be thus *electro-gilded.* In *electrotyping,* impressions of type or engravings are taken in wax, or any other plastic material that is impervious to water. A conducting surface is given to such a mould by brushing finely powdered graphite over it; it is then placed in a solution of sulphate of copper facing a copper plate. The mould is then connected with the — pole of a dynamo or a voltaic battery and the copper, with the + pole; when the current passes through the bath, copper will be deposited upon the mould. When the copper film is thick enough (say as thick as an ordinary visiting card), it is removed from the mould and strengthened by filling up its back with melted type-metal. The copper film and the type-metal are made to adhere by means of an amalgam of equal parts of tin and lead. The copper-faced plate thus produced is an exact reproduction of the type and engravings from which the mould was made.

(*a.*) In all these cases, the metal is carried in the direction of the current and deposited upon the negative electrode. In electroplating and gilding, the technicalities of the art refer chiefly to the means of making the deposit firmly adherent. In electrotyping, they refer chiefly to the preparation of the mould or matrix.

413. Electro-Chemical Series.—The facts just considered suggest a division of substances into two classes, electro-positive and electro-negative. *The ion that goes to the negative electrode is called electro-positive; that which goes to the positive electrode is called electro-negative.*

(*a.*) Kathions are called electro-*positive* because they seem to be attracted to the *negative* pole of the battery (kathode), the idea being that of attraction between opposite electricities. Hydrogen and the metals are kathions or electro-positive. They seem to move with the current, going as far as possible and being deposited where the current leaves the "bath" or electrolytic cell. Similarly, anions are said to be electro-negative.

414. The E. M. F. of Polarization.—The products of electrolysis have a tendency to reunite by virtue of their chemical affinity. (*Chemistry,* § 8.) For example, the electrolysis of zinc sulphate gives zinc and sulphuric acid. But we now well know that the chemical action of these two substances has an electro-motive force of its own. This E. M. F. of the ions acts in opposition to that of the electrolyzing current. In some cases, it rises higher than the E. M. F. of the original current *and reverses the direction of the current.* The oxygen and hydrogen, yielded by the electrolysis of water, tend to reunite and set up an opposing E. M. F. of about 1.45 volts, Thus we see that it requires a battery or cell with an E. M. F. of more than 1.45 volts to decompose water. *This electro-motive force of the ions is called the E. M. F. of Polarization.* It may be observed by putting a galvanometer in the place of the battery of the water-voltameter (Fig. 194). The polarization in a voltaic cell acts in the same way.

(*a.*) There is no opposing E. M. F. of polarization when the kathion and the anode are of the same metal. For example, the feeblest current will deposit copper from a solution of copper sulphate, *when the anode is a copper plate.*

Experiment 79.—Suspend two strips of bright sheet lead facing each other in dilute sulphuric acid. Pass a current through these plates by connecting them with a battery of 4 or 5 cells in series. A dark peroxide of lead will form on one of the bright plates. Then remove the battery and, in its place, put a short coil galvanometer or electro-magnet. It will be found that the lead-plate cell is supplying a current, the direction of which is the reverse of the charging battery previously used.

415. Secondary Batteries.—When a voltameter or an electro-plating bath is supplying a current of electricity, as mentioned in the last paragraph, it constitutes a secondary battery. As the ions do not reunite when the circuit is open, the energy of the decomposing current may be stored up as energy of chemical affinity. *When a current is again wanted, the circuit may be closed and the energy of chemical affinity at once appears as energy of electric current. Secondary batteries are, consequently, often called storage batteries.*

(*a.*) The Faure battery consists of two plates of sheet lead coated with red lead (lead sesqui-oxide, Pb_3O_4). These plates are separated by a layer of paper or cloth, rolled up in a loose coil like a roll of carpet and immersed in dilute sulphuric acid.

(*b.*) When a current from a dynamo-electric machine or a voltaic battery is sent through such a cell, chemical action is produced. Oxygen acts on the coating of the anode plate and converts it into a higher oxide of lead (the peroxide, PbO_2). Hydrogen acts upon the coating of the kathode plate and reduces it to metallic lead in a spongy condition. When these changes have gone as far as possible, the battery is said to be "charged." The charged plates will remain in this condition for days *if the circuit be left open.*

(*c.*) By closing the circuit, the plates will, at any time, furnish a current until they are changed to their original chemical condition. As the lead plates and the acid are not rapidly destroyed, the battery may be charged and discharged many times.

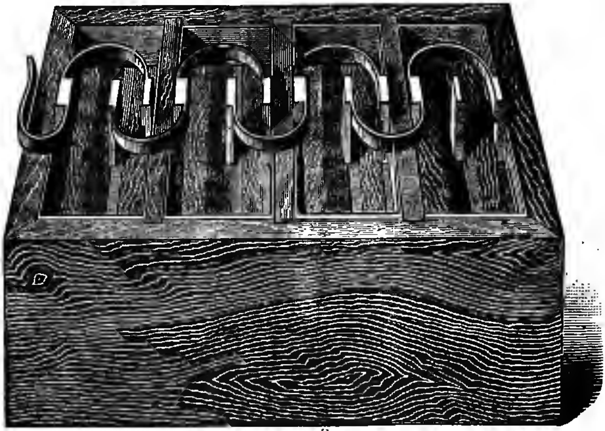


FIG. 196.

(*d.*) Many serious defects in the Faure battery have been obviated in the Brush battery (Fig. 196). These batteries are composed of a number of cells containing cast lead plates of a peculiar construction, electro-chemically prepared and immersed in dilute sulphuric acid. These cells may be connected together, tandem or abreast, so as to produce any desired result. A large number of these batteries may be placed in one circuit and charged by the current of one dynamo. It will thus be seen that the dynamo may be made to do double duty, charging batteries by day for use in connection with the incandescence lamps and supplying arc lamps direct, at night. The E. M. F.

of each Brush cell is about two volts. For electric lighting, they are generally prepared in batteries of twenty or more cells. An automatic current "manipulator" or switch is provided with each Brush battery and is arranged so as to retain the battery in circuit until it is charged and then to disconnect it from the circuit. When the charge has been exhausted to a certain point, it brings the battery into the circuit again and holds it till it has been recharged and then cuts it out as before. The same operation is repeated with every battery in circuit. The operation is automatic. Each battery has a clock attached, which registers the time that the charging current has been passing through the cells. The incandescence lamps are connected with the batteries through the "manipulator," as shown in Fig. 197. The quantity of electricity capable of being "stored" may be increased by increasing the number of cells and the size of the plates.

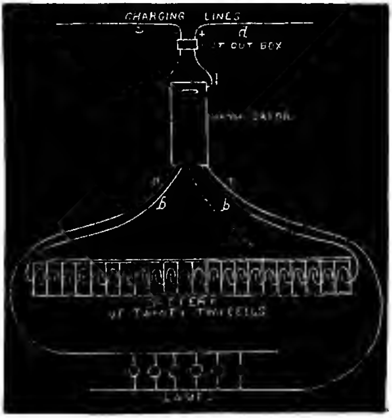


Fig. 197.

416. Magnetic Effects of the Electric Current.

—Any conductor is rendered magnetic by passing a current of electricity through it. A common needle may be magnetized by winding about it an insulated copper wire and discharging a Leyden jar through the wire. We have already seen that a bar of soft iron may be temporarily magnetized by the influence of the voltaic current. It may be further shown by the action of the bar and helix.

(*a.*) This apparatus consists of a movable bar of soft iron surrounded by a coil of insulated copper wire (Fig. 198). When the wire of the coil is placed in the closed circuit of a battery, the iron bar becomes strongly magnetized; when the circuit is broken, the bar instantly loses its magnetic power. The bar may be a straight piece of stout iron wire; the helix may be made by winding insulated copper wire upon a piece of glass tubing large enough to admit the wire and not quite as long as the iron.

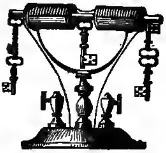


FIG. 198.

(*b.*) A good helix, convenient for many purposes, may be made upon an ordinary wooden spool. With a sharp knife, make the shank of the spool as thin as possible and then wind the spool full of insulated copper wire about as large as ordinary broom or stove-pipe wire. The iron bar must be small enough to pass easily through the hole in the spool and long enough to project a little ways beyond each end.

(*c.*) Either of these helices may be placed in the circuit of a cell and held in a vertical position, when it will act as a "sucking" magnet. The movable iron core will be held in mid-air "without any visible means of support."

(*d.*) The "helix and ring armature" is shown in Fig. 199. The armature is of soft iron divided into two semicircles with brass handles. When the helix is placed in a closed circuit, the semicircles resist a considerable force tending to draw them apart; when the circuit is broken, they fall asunder of their own weight. The iron ring may be made without handles by any blacksmith. Stout cords will answer for handles. The helix may be made by winding insulated wire upon a pasteboard cylinder an inch or an inch and a half long. There should be four or five layers of stout, copper wire which may be tied together with strings passing through the hole in the helix.

FIG. 199.

(*e.*) Such temporary magnets as these are called electro-magnets. The subject of electro-magnets will be further considered in §§ 442–448.

417. Deflection of the Magnetic Needle.—

We have already seen that the voltaic current has a marked effect in turning the magnetic needle from its north and south position, tending to place the needle at right angles to the direction of the current. This may be easily shown by Oersted's apparatus represented in Fig. 200. It consists of a magnetic needle and a brass wire frame with three pole-cups, permitting the current to be passed over, under, or around the magnet. *The space immediately surrounding a wire carrying an electric current is a field of magnetic force as truly as is the space around a magnetized body* (§ 433).

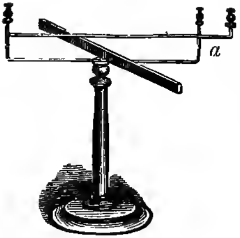


FIG. 200.

(*a.*) If the current pass *above* the needle from north to south, the north-seeking or — end of the magnet will be deflected toward the east; if it pass from south to north, the — end of the needle will be deflected toward the west. If the current pass *below* the needle, the deflections will be the opposite of those just mentioned. The wires are insulated where they cross at *a*.

418. The Astatic Galvanometer.—This galvanometer depends upon the principles set forth in the last paragraph. *It is a very delicate instrument for detecting the presence of an electric current and determining its direction and strength.* In Oersted's apparatus, the needle is heavy and a considerable force is needed to set it in motion; in the galvanometer, the needle is very light and suspended so as to turn easily. In Oersted's apparatus, the needle is held in the magnetic meridian by the directive influence of the earth; in the galvanometer, this is obviated almost wholly by the use of an astatic needle (§ 439). In Oersted's apparatus, the current makes but a single course about the needle; in the galvanometer, the wire is insulated and coiled many times about the needle; thus the effect is multiplied. One of the needles is within the coil while the other swings above it, the two being connected by a vertical axis passing through an appropriate slit in the coil. If both needles were within the coil, since their poles are reversed, the same current would tend to deflect them in opposite directions and thus the action of one needle would neutralize that of the other. The astatic needle is suspended by an untwisted silk fibre from a hook which may be lowered when the instrument is not in use until the upper needle rests upon the dial plate beneath it. The ends of the coiled wire are connected with binding screws; leveling screws are provided, by means of which the instrument may be adjusted so that the needles shall swing clear of all obstructions. A glass cover protects from dust and disturbance by air currents. The instrument is represented in Fig. 201.

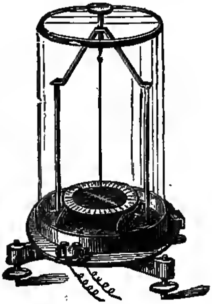


FIG. 201.

(*a.*) When the deflections of the astatic galvanometer are less than 10° or 15°, they are very nearly proportional to the strengths of the currents that produce said deflections. A current that deflects the needle 6° is about three times as strong as one that deflects it 2°.

(*b.*) That a galvanometer shall be good, it must be able to measure the strength of the current in some certain way. It must be adapted to the currents to be measured by it. A galvanometer fitted for the measurement of small currents (*e. g.*, five or six milliamperes) would not be suitable for measuring a ten ampere arc electric light current. If the current to be measured has passed through a circuit of great resistance (*e. g.*, several miles of telegraph wire), a short-coil galvanometer consisting of only a few turns of wire will not answer; a long-coil galvanometer, with many turns of wire about the needle, must be used. Hence, it will be seen that different kinds of galvanometers are needed for different kinds of work. (See Appendix L.)

Experiment 80.—Connect an iron and a German silver wire to the binding posts of a sensitive, short-coil, astatic galvanometer. Twist the free ends of the wires together and heat the junction in the flame of an alcohol lamp. *The deflection of the galvanometer-needle will show that an electric current is traversing the circuit.* Cool the junction with a piece of ice. The galvanometer will show that a second current is flowing in the opposite direction.

419. Thermo-Electricity. — *If a circuit be made of two metals and one of the junctions be heated or chilled, a current of electricity is produced.*

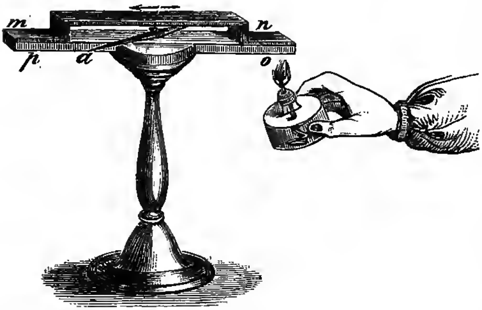


FIG. 202.

(*a.*) This may be further illustrated by the apparatus shown in Fig. 202. The upper bar, *m n*, having its ends bent, is made of copper; the lower, *o p*, is of bismuth. This rectangular frame is to be placed in the magnetic meridian and a magnetic needle placed within it. Upon heating one of the junctions, a current will be produced, the existence of which is satisfactorily shown by the deflection of the needle as indicated in the figure. The junction may be chilled with a piece of ice or by placing upon it some cotton wool moistened with ether. In this case, a current, opposite in direction to the first, will be produced; the needle will be turned the other way. The frame may be simplified by bending a strip of copper twice at right angles to make the top, bottom and one end of the frame, the other end being a cylinder of bismuth. But the form shown in Fig. 202 is preferable, as the same junction may be heated by the lamp below or chilled by laying a piece of ice on the upper side.

420. A Thermo-electric Pair.—If a bar of antimony, *A*, be soldered to a bar of bismuth, *B*, and the free ends joined by a wire, we evidently have a circuit equivalent to the one considered in the last paragraph. When the junction, *C*, is heated, a current will pass, from bismuth to antimony across the junction and from antimony to bismuth through the wire, as shown in Fig. 203.

(*a*.) The arrangement is analogous to a voltaic element, the antimony representing the — plate and carrying the + electrode, the bismuth representing the + plate and carrying the — electrode, while the solder takes the place of the liquid. The E. M. F. of an antimony-bismuth pair for 1° C. difference of temperature is about 117 microvolts. Just as a number of voltaic elements may be connected, so may a number of thermo-electric pairs be connected to form a thermo-electric series.

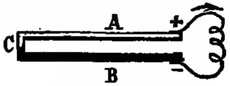


FIG. 203.

421. The Thermo-electric Pile.

— Several thermo-electric pairs, generally five, six, or seven, are arranged in a vertical series, as shown in Fig. 204, the intervening spaces being much reduced, the successive bars separated by strips of varnished paper only and the wire connection omitted. A similar series may be united to this by soldering the free end of the antimony bar of one series to the free end of the bismuth bar of the other, the two series being separated by a strip of varnished paper. Any desirable number of such series may be thus united, compactly insulated and set in a metal frame so that only the soldered ends are open to view. The free end of the antimony bar, representing the + electrode, and the free end of the bismuth bar, representing the — electrode, are connected with binding screws, which may be connected with a sensitive short-coil galvanometer. The thermo-electric

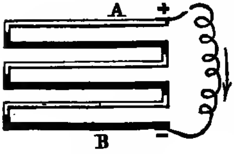


FIG. 204.

pile, with the addition of conical reflectors, is shown in Fig. 205. A change of temperature at either exposed face of the pile produces a feeble current of electricity which is manifested by the movement of the needle of the galvanometer. The instrument is much used in scientific work for detecting differences in temperature, being much more sensitive than the mercury thermometer.


FIG. 205.

422. The Peltier Effect.—When an electric current passes over a junction from antimony to bismuth, there is an evolution of heat at the junction, the temperature of which rises. When the current passes in the opposite direction (from bismuth to antimony), there is an absorption of heat and the temperature of the junction falls. In other words, if the current be sent through the circuit in the direction in which the thermo-electromotive force would naturally send it, the heated junctions will be cooled and the cooled junctions will be heated.

EXERCISES.

1. (*a.*) Draw a figure of a simple voltaic element. (*b.*) State what is meant by the electric current. (*c.*) Indicate, upon the figure, the direction of the current. (*d.*) What are the electrodes? (*e.*) Indicate them by their proper signs upon the figure.

2. (*a.*) Describe or figure a high resistance battery of Grove's elements. (*b.*) A low resistance battery of Bunsen's elements. (*c.*) What is the peculiar advantage of the Daniell's battery?

3. Describe an experiment illustrating the heating effects of current electricity.

4. (*a.*) How may a very feeble current be detected? (*b.*) Describe the apparatus used. (*c.*) Mention the features contributing to its delicacy.

5. (*a.*) If the resistance of one mile of a certain electric light wire is 3.58 ohms, what is the resistance of 4.4 miles of the same wire? (*b.*) The resistance of a certain wire is 5 ohms per 100 yd. What length of the same wire will have a resistance of 13.2 ohms?

Ans. (*a.*) 15.75 ohms. (*b.*) 264 yd.

6. What is the resistance of a mile of copper wire that has a diameter of 65 mils if the resistance of a mile of copper wire 80 mils in diameter is 8.29 ohms? *Ans.* 12.56 ohms.

7. If the resistance of 700 yd. of a certain wire is 0.91 ohm, what is the resistance of 1,320 yd.? *Ans.* 1.72 ohm.

8. (*a.*) Define electrolyte. (*b.*) What term is applied to chemical decomposition when effected by means of an electric current? (*c.*) How would you go about the task of determining for yourself the electro-chemical nature of a substance?

9. The resistance of a certain wire is 4.55 ohms. The resistance of a mile of the same wire is 1.3 ohms. What is the length of the first wire? *Ans.* 3.5 mi.

10. The resistance of a mile of copper wire 70 mils in diameter is 10.82 ohms. What is the diameter of a copper wire a mile long and having a resistance of 23 ohms? *Ans.* 0.048 inch or 48 mils.

11. What should be the length of a silver wire so that it may have the same resistance as 10 inches of copper wire of the same thickness, the conductivity of silver being 1.0467 times that of copper?

12. Find the resistance, at the freezing temperature, of 20 *m.* of German silver wire weighing 52.5 grams, having given that the resistance, at the same temperature, of a wire of the same material 1 *m.* long and weighing 1 *g.* is 1.85 ohms. *Ans.* 14.1 ohm.

13. When a piece of fine platinum wire and a galvanometer are put in the circuit of a galvanic cell, the needle is deflected. Remove the platinum wire and close the circuit with stout copper wire; the needle is deflected more than before. Explain.

14. Find the resistance of 500 yd. of copper wire 165 mils in diameter, the resistance of one mile of copper wire 230 mils in diameter being one ohm. *Ans.* 0.55 ohm.

15. If 1,000 ft. of wire 95 mils in diameter have a resistance of 1.15 ohm, what is the diameter of a wire of the same material that has a resistance of 10.09 ohms per 1,000 ft.? *Ans.* 32 mils.

16. Under what circumstances is it desirable to arrange cells as shown in Fig. 206?

17. A copper wire 6 *m.* long has a diameter of 0.74 *mm.* What is the length of a copper wire of 1 *mm.* diameter that has the same electrical resistance? *Ans.* 10.957 *m.*

18. Given 8 cells, each with an E. M. F. of 2 volts and an internal resistance of 8 ohms. The resistance of the external circuit is to be 16 ohms. How shall the cells be arranged to give maximum current and what will that current be? *Ans.* 0.25 ampere.

19. What is the length of an iron wire having a sectional area of 4 *sq. mm.* and the same resistance as a copper wire 1,000 yd. long, the latter having a sectional area of 1 *sq. mm.*, the conductivity of iron being $\frac{1}{7}$ that of copper? *Ans.* 571$\frac{3}{7}$ yd.

20. Two incandescence lamps of 31 and 37 ohms respectively are placed abreast in a circuit. Find the joint resistance of the two lamps. *Ans.* 16.87 ohms.

21. How thick must an iron wire be so that it and a copper wire that has the same length and a diameter of 2.5 *mm.* shall have the same resistance, the resistance of iron being 7 times that of copper?

Ans. 6.61 *mm.*

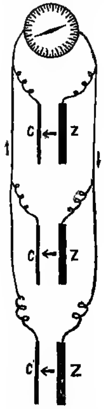


FIG. 206.

22. How many coulombs will be furnished by the consumption of 20 *g.* of zinc?

23. What weight of zinc must be consumed in each cell of a voltaic battery of 3 Daniell's cells to enable the electrolysis of 9 *g.* of water? (Neglect loss by local action.) *Ans.* About 32.5 *g.*

24. What weight of copper will be deposited in each cell of the battery mentioned in the last problem? *Ans.* About 31.5 *g.*

25. Three wires, the respective resistances of which are 5, 7 and 9 ohms are joined in multiple arc. Find the resultant resistance of this compound conductor. *Ans.* 2.2 ohms.

26. What is the necessary E. M. F. of a dynamo that is to furnish a 10 ampere current for 60 arc lamps (in series), each of which has a resistance of 4.5 ohms, the resistance of the line wire being 10 ohms and the internal resistance of the dynamo being 22 ohms?

27. A piece of zinc, at the lower end of which a piece of copper wire is fixed, is suspended in a glass jar containing a solution of acetate of lead (sugar of lead). After a few hours, a deposit of lead in tree-like form grows downward from the copper wire. Explain this.

28. Liquids increase in conductivity with an increase of temper-

ature. Will a given battery give a stronger current at 0° C. or at 20° C.?

29. What should be the length of a lead wire so that it may have the same resistance as 10 inches of copper wire of the same thickness, the conductivity of lead being 0.0923 times that of copper?

30. Four wires are joined together in multiple arc, their resistances being 5.5, 18, 3.7 and 2.9 ohms respectively. Find the resultant resistance of the compound conductor thus formed.

Ans. 1.17 ohm.

HONORARY PROBLEM.

31. Find the number of incandescence lamps that may be worked in multiple arc by a dynamo-electric machine that has an internal resistance of 0.032 ohm. The E. M. F. of the dynamo is 55 volts and the resistance of each lamp is 28 ohms. The current must be 1.6 amperes in each lamp. *Ans.* 199 lamps.

Recapitulation.—To be amplified by the pupil for review.

- CURRENT ELECTRICITY.
  - CHEMICAL ACTION.
    - VOLTAIC.....
      - Cell.......
        - *One Liquid..*
          - Smee's.
          - Potassium di-chromate.
          - Leclanché.
        - *Two Liquids.*
          - Daniell's.
          - Callaud's.
          - Grove's.
          - Bunsen's.
        - *Joined........*
          - Tandem.
          - Abreast.
          - Best Method.
      - Source of Energy.
      - Battery. ..
        - *High Internal Resistance.*
        - *Low Internal Resistance.*
        - *Requisites.*
      - Current...
        - *Direction*
        - *Strength......*
          - Unit.
          - Ohm's Law.
    - CIRCUIT.....
      - Simple.
      - Divided.
      - Shunt.
    - SIGN OF.....
      - Plate.
      - Pole.
      - Electrode.
        - *Anode.*
        - *Kathode.*
    - POTENTIAL; Fall of E. M. F.
      - *Unit.*
      - *Measurement.*
    - RESISTANCE ....
      - External.
      - Internal.
      - Laws.
      - Unit.
      - Measurement.
      - Long and Short-Coil Instruments.
    - QUANTITY ;........Unit.
    - LOCAL ACTION.
      - Cause.
      - Remedy.
    - POLARIZATION.
      - Cause.
      - Remedy.
  - EFFECTS.
    - MECHANICAL.
    - THERMAL;........Relation to Resistance.
    - LUMINOUS.
    - PHYSIOLOGICAL.
    - CHEMICAL... ...
      - Electrolysis.
        - *Anion.*
        - *Kathion.*
          - Ions.
      - Electro-Metallurgy.
      - Electro-Chemical Series.
      - E. M. F. of Polarization.
      - Secondary Batteries..
        - *Faure's.*
        - *Brush's.*
        - *Uses.*
        - *Advantages.*
    - MAGNETIC........
      - Electro-Magnets.
      - Electric Telegraph.
      - Galvanometer.
  - THERMO-ELECTRICITY.

(*For Induced Currents, see Section V. of this Chapter.*)

SECTION IV.

MAGNETISM.

423. Natural Magnets.—One of the most valuable iron ores is called magnetite ($Fe_3 O_4$). Occasional specimens of magnetite will attract filings and other pieces of iron. *Such a specimen is called a lodestone.* It is a natural magnet.

424. Artificial Magnets.—Artificial magnets are either temporary or permanent. A temporary magnet is usually made of soft iron and is called an electro-magnet. A permanent magnet is usually made of steel. Artificial magnets have all the properties of natural magnets and are more powerful and convenient. They are, therefore, preferable for general use. The most common forms are the straight or *bar* magnet and the *horseshoe* magnet. The first of these is a straight bar of iron or steel; the second is shaped like a letter U, the ends being thus brought near together, as shown in Fig. 207. A piece of iron placed across the two poles of a horseshoe magnet is called an *armature.* We have already learned how to make artificial magnets.

FIG. 207.

425. Retentivity.—It is more difficult to get the magnetism into steel than into iron. It is also more difficult to get it out. *This power of resisting magnetization or demagnetization is called coercive force or retentivity.* The harder the steel, the greater its retentivity. Soft wrought iron has but little retentivity.

426. Distribution of Magnetism.—If a bar magnet be rolled in iron filings and then withdrawn, the filings cling to the ends of the bar but not to the middle. This form of attraction is not evenly distributed throughout the bar. *It is greatest at or near the ends. These points of greatest attraction are called the poles of the magnet.* It is impossible, by any known means, to develop one magnetic pole without simultane-

FIG. 208.

ously developing another pole of opposite sign. The middle of the magnet does not attract iron and is called the *equator or neutral point.*

Experiment 81.—Bring either end of a bar magnet near the end of a floating piece of iron, AB; the iron is attracted. Bring the same end of the magnet near the middle of the iron; the iron is attracted. Bring the same end of the magnet near the other end of the iron; the iron is attracted. Repeat the experiments with the other end of the magnet; in each case, the iron is attracted.

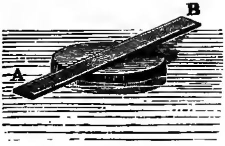


FIG. 209.

427. Attraction between a Magnet and Iron.—*Either pole of a magnet will attract ordinary iron.*

Experiment 82.—Freely suspend three bar magnets, A, B and C, at some distance from each other. This may be done by placing each magnet in a stout paper stirrup supported by a cord or horse-hair or upon a board or cork floating on water. (See Fig. 209.) *When they have come to rest, each will lie in a north and south line.* Magnets for this experiment may be made by magnetizing (§ 448) three stout knitting-needles. If there is any electric light apparatus in your neighborhood in charge of a good-natured man, he will probably magnetize the needles for you. Each needle may be suspended by means of a triangular piece of stiff writing-paper. Pass the needle through the paper near the lower corners; at the other corner, affix, by wax, the end of a horse-hair. The poles may be indicated by little bits of red and of white paper, fastened by means of wax to the ends of the needles. Mark the north-seeking poles, — and the south-seeking poles, +.

428. Characteristics of Magnets.—*Magnets are chiefly characterized by the property of attracting iron and by a tendency to assume a particular direction of position when freely suspended.*

Experiment 83.—(*a*.) Take magnet A of Experiment 82 from its support and bring its + end near the − end of *B* or *C*. Notice the attraction.

(*b.*) Bring the + end of *A* near the + end of *B* or *C*. Notice the repulsion.

(*c.*) Bring the − end of *A* near the − end of *B* or *C*. Notice the repulsion

(*d.*) Bring the − end of *A* near the + end of *B* or *C*. Notice the attraction.

(*e.*) From (*a.*), we learned that the − ends of *B* and *C* were each attracted by the + end of *A*. Bring the − end of *B* near the − end of *C*. Notice that they now repel.

(*f.*) From (*b.*), we learned that the + ends of *B* and *C* were each repelled by the + end of *A*. Bring the + end of *B* near the + end *C*. Notice that they now repel.

(*g.*) In similar manner, show that the + end of *B* will attract the − end of *C*; that the − end of *B* will attract the + end of *C*.

Record the results of your experiments in tabular form thus:

(*a.*) + attracts −.	(*b.*) + repels +.
(*d.*) − attracts +.	(*c.*) − repels −.
etc.	*etc.*

Experiment 84.—Magnetize a number of fine sewing-needles by drawing the + end of a bar magnet three or four times from the eye to the point of each. Cut several small corks into slices about an eighth of an inch thick. Through each cork disc, push a needle up to its eye and place them in a round dish of water. These little magnets have their like poles presented to each other and they mutually repel. Bring the bar magnet, with its + end downward, over the needles; they will be driven to the sides. Similarly, bring the — end over them; they will be attracted toward the centre.

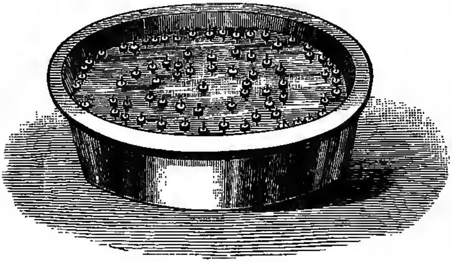


FIG. 210.

429. Laws of Magnets.—(1.) *Every magnet* *has two similar poles; like poles repel each other; unlike poles attract each other.*

(2.) *Magnetic force, like other forms of attraction and repulsion, varies inversely as the square of the distance.*

Experiment 85.—Dip one of the magnetized knitting-needles into iron filings. Notice that filings cling to the ends, near the paper discs, but that none cling to the middle. Break the needle in the middle and dip each piece into iron filings. Notice that the unmarked ends, which were at the middle of the unbroken magnet, now attract iron filings as well as do the marked ends. *Poles have been developed in parts of the needle that previously showed no magnetic attraction.*

430. Effect of Breaking a Magnet.—If a magnet be broken, each piece becomes a magnet with two poles and an equator of its own. These pieces may be repeatedly subdivided and each fragment will be a perfect magnet.

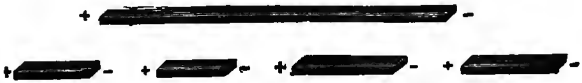


FIG. 211.

It is probable that every molecule has its poles or is polarized and that, could one be isolated, it would be a perfect magnet. We may, thus, conceive a magnet as made up of molecules each of which is a magnet, the action of the molar magnet being due to the combined action of all the molecular magnets of which it is composed.

431. Magnetized, Magnetic and Diamagnetic Substances.—A *magnetized* body is one that can be made to repel a pole of a freely suspended magnet. Substances that are attracted by a magnet are called *magnetic; e.g.*, iron or steel and nickel. Substances that are repelled by a magnet are called *diamagnetic; e.g.*, bismuth, antimony, zinc, tin, mercury, lead, silver, copper, gold and arsenic. Of these, iron is by far the most magnetic, while bismuth is the most diamagnetic. The magnetic properties of iron or steel are easily shown; diamagnetic properties require a powerful magnet for satisfactory illustration.

Experiment 86.—Wrap a bar magnet in a piece of cloth. With it, attract and repel the poles of a suspended magnet.

Experiment 87.—Repeat the last experiment, holding a slate or sheet of zinc between the two magnets.

Experiment 88.—Put one piece of the broken magnet into a bottle; cork the bottle tightly. With it, attract and repel the poles of a suspended magnet.

432. Magnetic Screens.—*Nothing but a magnetic body can cut off the inductive action of a magnet.* If a small magnet be suspended inside a hollow iron ball, no outside magnet will affect it.

Experiment 89.—With the end of a good bar magnet, write your name upon the blade of a handsaw. The invisible characters may be made visible by sifting fine iron filings upon the blade.

Experiment 90.—Place a piece of card-board or rough drawing paper over a good bar magnet. Sift fine iron filings through a piece of muslin upon the card-board and tap it lightly. The iron particles will move and arrange themselves in well defined curved lines. (See Fig. 212.) By using two bar magnets placed side by side, *first*, with like poles near each other and, *secondly*, with unlike poles near each other, their combined effect on the iron filings may be easily observed. The figures will be widely different.

433. Magnetic Field.—A magnet seems to be surrounded by an atmosphere of magnetic influence called *the magnetic field.* (See § 450*d* and Appendix N.) The magnetic curves, formed in the above experiment, are very interesting and instructive for they show the direction of *the lines of magnetic force.* The filings in any one of these curves are temporary magnets with adjoining poles opposite and therefore attracting. If a small magnetic needle be suspended over the card-board at any point, its length will tend to lie in the direction of the lines of magnetic force at that point as mapped out by the iron filings.

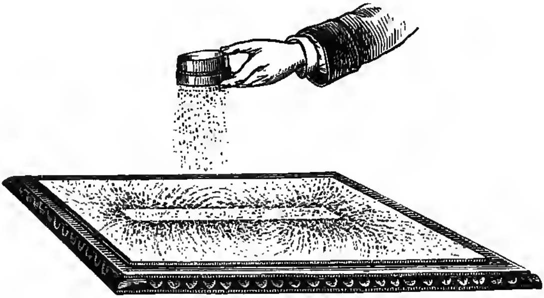


FIG. 212.

(*a.*) The figures may be permanently fixed by using a sheet of glass that has been gummed and dried, instead of the sheet of paper. The filings are sifted evenly over the surface; then the glass is tapped; then a jet of steam is caused to play gently above the sheet, softening the surface of the gum, which, as it hardens, fixes the filings in their places.

(*b.*) Since the lines of force are made of little magnetic particles that set themselves thus in obedience to the attractions and repulsions in the field, they represent the resultant direction of said forces at each point. They map out the magnetic field, showing the direction of the magnetic force by their position and its intensity by their number. If a small − pole could be obtained alone and put down on any one of these lines of force, it would tend to move along that line from + to − ; a single + pole would tend to move along the line in an opposite direction.

Experiment 91.—Rub *one end* of a steel pen against the end of a magnet. Dip the pen into iron filings and notice that the newly made magnet has a pole at *each end.* Determine the sign of each of these poles, as indicated in Experiment 82.

434. Magnetization by Contact.

—*A bar of iron or steel may be magnetized by rubbing it against a magnet.* Pure or soft iron is easily magnetized but quickly loses its magnetism when the magnetizing influence is removed. Hardened steel is magnetized with more difficulty but retains its magnetism after the removal of the magnetizing influence.

Experiment 92.—Move the point of an unmagnetized steel pen to and fro very near one end of a magnet but without touching it to the magnet. Dip the pen into iron filings and determine whether or not it has been magnetized. If it has, determine the sign of each pole, as in the last experiment and notice whether the point of the pen is of the same polarity as the end of the magnet near which it was moved.

Experiment 93.—Bring a short bar of soft iron, *I*, very near a strong bar magnet, *M*, end to end, as shown in the figure. Sprinkle iron filings over the ends of the iron bar and they will cling as they would to a magnet. *The iron bar is a magnet, while it remains in this position.*

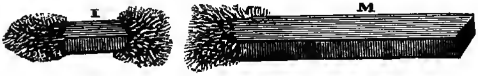


FIG. 213.

435. Magnetic Induction.

—If the end of a bar of soft iron be brought near one of the poles of a strong magnet, *the iron becomes, for the time being, a magnet.* The poles of the temporary magnet will be opposite to those of the permanent magnet, *i.e.*, if the + or positive pole of the magnet be presented to the iron bar, it will develop a — or negative pole in the nearest end of the iron bar and a + pole at the further end. Bring the iron bar nearer the magnet and this effect will be increased. Actual contact is not necessary, but when the iron and the magnet touch, the magnetizing force is the greatest. If a steel bar be used instead of an iron bar, it will be permanently instead of temporarily magnetized. *The iron or the steel is induced to become a magnet by the influence of the magnet used. It is said to be magnetized by induction.* This, like other forms of attraction, varies inversely as the square of the distance. We have already seen that magnetic induction takes place in certain directions called lines of magnetic force (§ 433.)

Experiment 94.—Bring a soft iron ring to the end of a magnet. It will be supported. Bring a second ring into contact with the first ring and it will be supported. In this way, quite a number of rings may be supported, each ring being magnetized by the bar or ring magnet above it. Of course, the attractive force is continually weakening from the first to the last ring. Support the upper ring upon your finger and remove the magnet. Each ring ceases to be a magnet and the chain is broken into its separate links. Vary the experiment by using, instead of the rings: (1,) Soft iron nails; (2,) Steel sewing-needles; and see if there is any difference in the results.

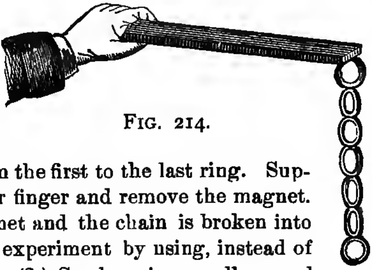


FIG. 214.

Experiment 95.—Suspend an iron key from the positive end of a bar magnet. The key is inductively magnetized, the relation of its poles to each other and to the magnet being as shown in Fig. 215. A second bar magnet of about the same power, with its poles opposite, is moved along the first magnet. *When the — end of the second magnet comes over the key, the key drops.*

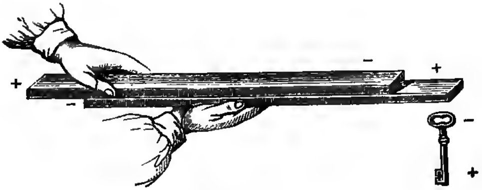


FIG. 215.

The first magnet tends to induce a — pole at the upper end of the key. The second magnet tends to induce a + pole at the same point. The effect of each magnet neutralizes that of the other.

Experiment 96.—Magnetize a piece of watch spring about six inches long (easily obtainable at the watch repairer's) by drawing it several times between the thumb and the end of a magnet. Dip it into iron filings. Lift it carefully with its load. Bring the poles of the spring magnet together, bending the magnet into a ring. *The magnet drops its load.*

FIG. 216.

436. Induction Precedes Attraction.

—We now see why a magnet attracts ordinary iron; it first magnetizes it and then attracts it. The attraction between unlike poles is greater than the repulsion between like poles because of the smaller distance between them. Compare § 336.

Experiment 97.—Test a common fire poker for magnetism by bringing a small magnetic needle near its ends and seeing whether the poker *repels* either pole of the compass needle or whether the two ends of the poker attract *different* poles of the needle. If the poker is not even slightly magnetic, place it with its upper end sloping toward the south so as to make an angle of a little less than half a right angle. In other words, place it in the position assumed by the dipping needle. (§ 439.) While the poker is in this position, strike it a few blows with a wooden block or mallet. Test it again for magnetism. A steel poker that has usually stood in a nearly vertical position may, thus, often be shown to have acquired magnetism.

437. The Earth is a Magnet.—The earth acts like a huge magnet in determining the direction of compass and dipping needles. Its inductive influence, as shown in the last experiment, strengthens the belief that it has such action. If a small dipping needle be placed over the — end of a bar magnet, the needle will take a vertical position with its + end down. As the needle is moved toward the other end of the bar, it turns from its vertical position. When over the neutral line, the needle is horizontal. As it approaches the + end of the magnet, the needle again becomes vertical, but the — end of the needle is drawn down. If a dipping needle be carried from far southern to far northern latitudes, it will act in a similar way. Many facts seem to teach that *the earth is a great magnet with magnetic poles near its geographical poles.* The magnetic pole in the northern hemisphere was found in 1832 by Capt. Ross. It was then a little north and west of Hudson's Bay, in latitude

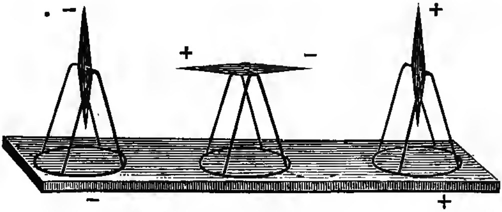


FIG. 217.

70° 05′ N., and longitude 96° 45′ W. A place in the southern hemisphere has been found where the dipping needle is *nearly* vertical.

438. Names of Magnetic Poles.—We have now learned to regard the earth as a huge magnet, with one pole in the northern hemisphere and one in the southern. Since unlike poles attract each other, it follows that *the earth's magnetic pole situated in the northern hemisphere is opposite, in kind, to the end of a magnetic needle that points to the north.* From this fact, great confusion of nomenclature has arisen. We have spoken of the end of the needle that points north as – or negative. Following this nomenclature, the northern magnetic pole of the earth must be + or positive. But popular usage calls the north-seeking end of the needle the north pole and the other end the south pole. This introduces great confusion when we wish to speak of the magnetic poles of the earth. The nomenclature that we have adopted obviates this confusion.

Experiment 98.—Make a horizontal needle of a piece of watch spring about six inches long and straightened by drawing it between thumb and finger. Heat the middle of the needle to redness in a flame and bend it double. Bend the ends back into a line with each other, as shown in Fig. 218. Magnetize each end separately and oppositely. Wind a waxed thread around the short bend at the middle to form a socket and balance the needle upon the point of a sewing-needle thrust into a cork for support. A little filing, clipping with shears or loading with wax may be necessary to make it balance. The needle will point north and south.

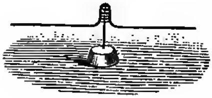


FIG. 218.

Experiment 99.—By means of a fine wire fork, gently lay one of the magnetized sewing-needles of Experiment 84 on the surface of water. It will float without any cork or similar support and will assume a north and south position. It may be considered the needle of a small compass.

439. Magnetic Needles.—*A small bar magnet suspended in such a manner as to allow it to assume its chosen position is a magnetic needle. It may turn in a horizontal or a vertical plane.*

(*a.*) If it be free to move in a horizontal plane, it is a horizontal needle; *e. g.*, the mariner's or the surveyor's compass (Fig. 219). It will come to rest pointing nearly north and south. If the magnet be free to move in a vertical plane, it constitutes a vertical or dipping needle (Fig. 220). Two magnets fastened to a common axis but having their poles reversed constitute an astatic needle (Fig. 221). An astatic needle assumes no particular direction with respect to the earth if the two needles are equally magnetized. (§ 418.)


FIG 219.

(*b.*) Make a dipping needle by thrusting a knitting-needle through a cork so that the cork shall be at the middle of the needle. Thrust through the cork, at right angles to the knitting-needle, half a knitting-needle, or a sewing-needle, for an axis. Support the ends of the axis upon the edges of two glass goblets or other convenient objects. Push the knitting-needle through the cork so that it will balance upon the axis like a scale-beam. Magnetize the knitting-needle and notices the *dip.*

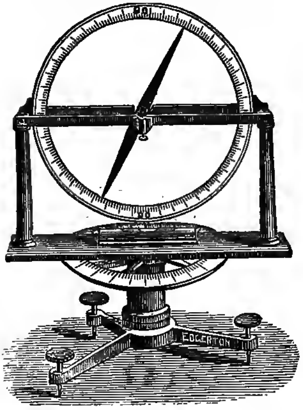


FIG. 220.

(*c.*) A magnetized sewing-needlé, suspended near its middle (at its centre of gravity) by a fine thread or hair or an untwisted fibre will serve as a dipping needle. It should first be suspended so as to hang horizontal and magnetized afterward. A simple form of dipping needle is represented in Fig. 222.

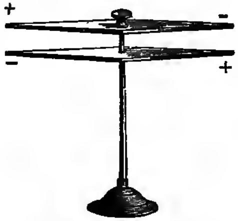


FIG. 221.

440. Inclination or Dip.—

The angle that a dipping needle makes with a horizontal line is called its inclination or dip. The angle in question is indicated by the dotted arc of Fig. 222. At the magnetic poles, the inclination is 90°; at the magnetic equator, there is no inclination. The inclination at any given place is not greatly different from the latitude of that place.

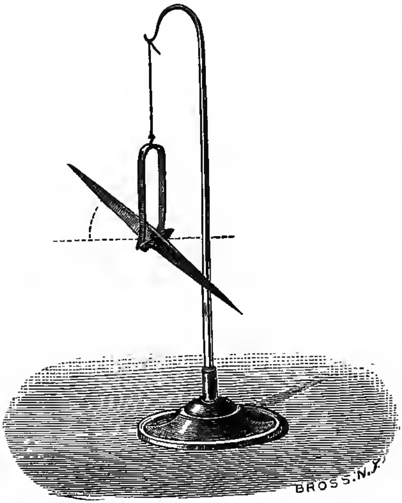


Fig. 222.

(*a.*) Experiments for inclination are difficult of execution without special apparatus. It is difficult to make a needle turn about a point exactly coincident with its centre of gravity. In rough experiments, there is danger that the magnetic effect will be masked by the effect of gravity.

Fig. 223.

Experiment 100.—Set two stakes so that a string joining them will point toward the North Star. The string will run north and south or nearly enough so for our purpose. Place a long magnet suspended as a needle under or over the string. Looking downward at the magnet and the string, it will probably be found that the needle and the string do not point in the same direction. The North Star may be easily found any evening in the direction indicated by "The Pointers" of the well known constellation, "The Great Dipper." "The Pointers" are the two stars marked by the Greek letters a and β in Fig. 223.

441. Declination or Variation.—The magnetic needle, at most places, does not lie in an exact north and south line. *The angle that the needle makes with the geographical meridian is its declination or variation.* A line drawn through all places where the needle points to the true north is called *a Line of no Variation.* Such a line, nearly straight, passes near Cape Hatteras, a little east of Cleveland, Ohio, through Lake Erie and Lake Huron. It is now slowly moving westward. At all places east of the Line of no Variation, the — end of the needle points west of the true north; at all places west of the Line of no Variation, the variation is easterly. The further a place is from this line, the greater the declination, it being 18° in Maine and more than 20° in Oregon.

(*a.*) In order that ships may steer safely by the compass, magnetic charts are prepared. The declination at various places is properly indicated on the chart. The surveyor must recognize not only the declination of his needle but also the changes in declination. Otherwise he would not be able properly to "run the lines" of a given piece of land from the description given in an old deed.

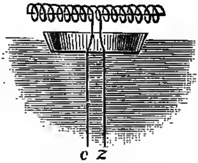


FIG. 224.

Experiment 101.—Construct a floating cell of zinc and copper plates, about ¼ inch apart, the connecting wire being given an elongated spiral or *solenoid* form, and support it by a large, flat cork resting on the surface of a bowlful of acidulated water, as shown in Fig. 224. The solenoid may be made by winding the middle part of about 3 yards of No. 20 insulated copper wire around a rod, half an inch in diameter, forming thus a coil, 4 or 5 inches long. The current will set the axis of the solenoid in a north and south direction as if it were a magnetic needle. By holding one end of a bar magnet near first one end and then the other end of the solenoid, it will be found that the latter exhibits magnetic polarity.

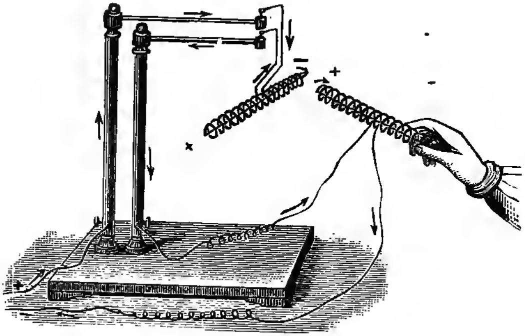


FIG. 225.

Experiment 102.—Support a solenoid by placing the extremities of its wire (bent into the same vertical axis) in two mercury cups, as shown in Fig. 225, or use the solenoid of the floating battery above described. Bring the end of a second solenoid successively to the ends of the first and notice the exhibition of magnetic polarity.

Experiment 103.—Send a current of electricity from the small cell, mentioned in Experiment 16, through its wire. Pour half a teaspoonful of iron filings upon a sheet of paper and bring the wire conductor of the cell into contact with the filings. Notice that the filings cling to the wire as though it were a magnet. Break the circuit and notice that the filings fall from the wire.

442. Electro-Magnets.—From these experiments, we see that while the wire conductor is carrying an electric current it has the properties of a magnet. We have already seen that, under similar circumstances, the conductor deflects a magnetic needle as if it were itself a magnet. In fact, such a conductor is a temporary magnet. The magnetic effect is much increased if a considerable length of the conductor be made of insulated wire and wound into a coil, as shown in Fig. 226. Such a coil is called a *helix;* it is a magnet with a + pole at one end and a — pole at the other. It has an easily perceptible magnetic field. If a soft iron rod or core be introduced into the coil, it enters the magnetic field of the coil or helix and becomes a magnet. This combination of coil and core constitutes an electro-magnet and is more powerfully magnetic than the coil alone. *An electro-magnet is a bar of iron surrounded by a coil of insulated wire carrying a current of electricity.* It may be made more powerful than any permanent magnet but loses its power as soon as the current ceases to flow through its coil. The fact that the magnetism of this apparatus is under control adapts it to many important uses, such as electric bells and telegraphic instruments.

FIG. 226.

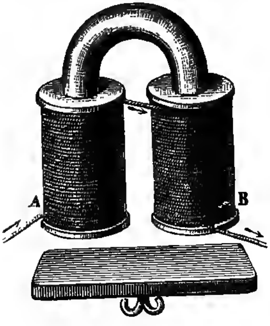


FIG. 227.

443. Forms of Electro-Magnets.—The bar of § 416, *a*, and the ring of Fig. 199, with their helices, are electro-magnets. The electro-magnet more often has the horse-shoe form shown in Fig. 227, so that the attraction of both poles may act upon the same body at the same time. The middle of the bent-bar is bare, the direction of the windings on the ends being such that, were the bar straightened, the current would move in the same direction round every part. More frequently, the two helices, *A* and *B*, have separate cores which are joined by a third straight piece into which the ends of the cores are screwed. An armature is often placed across the two poles of the magnet, as shown in the figure. Electro-magnets have been made capable of supporting several tons.

(*a*.) When the circuit is broken and the current thus interrupted, the iron is generally not *wholly* demagnetized. The small magnetism remaining is called *residual magnetism*. The residual magnetism seems to increase with the hardness and impurity of the iron. The cores of electro-magnets for some purposes are made of the softest and purest iron obtainable.

444. The Electric Telegraph.—The electric telegraph consists essentially of an electro-magnet and a "key" placed in the circuit of a battery. The key is an instrument by which the circuit may be easily broken or closed at will. The armature, *A*, of the "register" magnet, *M*, is supported by a spring, *S*, which lifts it when the circuit is broken. When the circuit is closed, the armature is drawn down by the attraction of the magnet. Thus, the armature may be made to vibrate up and down at the will of the person at the key. The

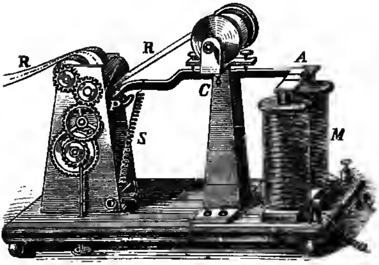


FIG. 228.

armature may act upon one arm of a lever, the other end of which, being provided with a style or pencil, *P*, may be pressed against a paper ribbon, *R*, drawn along by clockwork. Thus, the pencil may be made to record, upon the moving paper, a series of dots and lines at the pleasure of the operator at the key perhaps hundreds of miles away. When the two stations are several miles apart, one of the wires is dispensed with, the circuit being completed by connecting each station with the earth. This arrangement saves half the wire and nearly half the cost of the line. As the resistance of the earth is insignificant, there is the further saving of nearly half the battery otherwise necessary. Earth connections are often made by joining the wires to water or gas pipes that run into the ground. When the line is long, there is a battery at each end, the + electrode of one battery and the — electrode of the other battery being joined to the line wire. The same principle of communicating signals by making and breaking an electric circuit is used in fire and burglar alarms, hotel annunciators, *etc.*

445. Morse's Alphabet.—The inventor of the practical electric telegraph was an American, S. F. B. Morse. The code of signals devised by him is given below:

	LETTERS.		FIGURES.
a —	*k* — - —	*u* - - —	1 - — — -
b — - - -	*l* ——	*v* - - - —	2 - - — - -
c - -	*m* — —	*w* - — —	3 - - - — -
d — - -	*n* — -	*x* - — - -	4 - - - - —
e -	*o* - -	*y* - - - -	5 — — —
f - — -	*p* - - - - -	*z* - - -	6 - - - - - -
g — — -	*q* - - — -	*&* - - - -	7 — — - -
h - - - -	*r* - - -	, - — - —	8 — - - - -
i - -	*s* - - -	? — - - — -	9 — - - —
j — - — -	*t* —	. - - — —	0 ———

(*a.*) To prevent confusion, a small space is left between successive letters, a longer one between words and a still longer one between sentences. We here give a short message written in Roman and in telegraphic characters;

H e w i l l c o m e a t t e n .

.... .-- .. — — .. . . . — — . .- — — . — . ..— —..

The ordinary telegraph operator does not punctuate his messages to any considerable extent. Telegraph operators soon become so familiar with this alphabet that they understand a message from the mere clicks of the lever and do not use any recording apparatus. Such an operator is said to "read by sound"; his instrument is called a "sounder." Fig. 229 represents one. The sounder is placed on a local circuit and has a usual resistance of from three to five ohms.

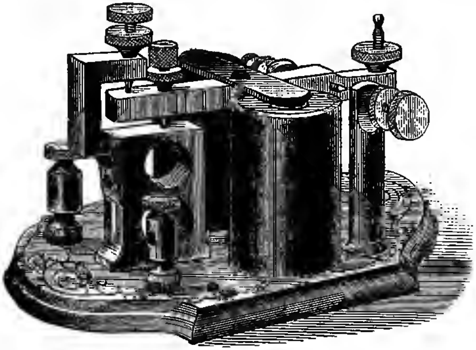


FIG. 229.

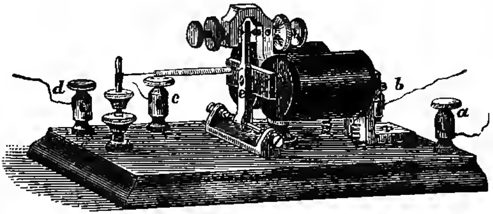


FIG. 230.

(*b.*) With a long main line, the resistance is so great that the current of the main battery is too feeble to operate the sounders with sufficient force. This difficulty is met by introducing a "local battery" and a "relay" at each station on the line. The relay (Fig.230) is a delicate electro-magnet, of which the terminals, *a* and *b*, are connected with the main line. This magnet operates an armature lever, *e*, the end of which strikes against a metal contact piece and thus closes the local circuit through the terminals, *c* and *d*. The resistance of relays vary from 50 to 500 ohms. The "Western Union" standard relay has a resistance of 150 ohms.

(*c*.) The arrangement of instruments is best studied at a telegraph station, one or more of which may be found at almost any town or railway station. The general features of the "plant" are represented by the diagram shown in Fig. 231. The pupil will probably find the key, sounder and relay on a table and the local battery, *b*, under the table. The keys being habitually closed, the current passes through all relays on the line, the current being continuous (§ 395) except when a message is being sent from some office. When an operator, in sending a message, opens his key, the breaking of the circuit stops the current, demagnetizes the relays and allows their springs to draw back the armature levers, *e*. This breaks each local circuit and demagnetizes each sounder, the spring of which raises its armature. Things are now as shown in the diagram, which also represents the condition of affairs at every other station on the line. When a message is sent from any station, each relay lever, *e*, acts as a key to its local circuit, it and the

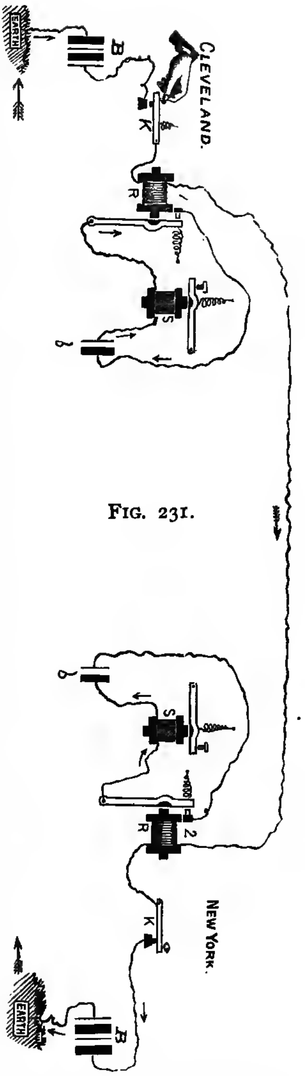


FIG. 231.

sounder lever vibrating in obedience to the motions of the key at the sending station. Of course, the sending operator can read his own message from his sounder. The message may also be read from any sounder on the line.

(*d.*) If the local circuit at New York (see Fig. 231) be lengthened so as to reach thence to Boston and the local battery, *b*, be increased to the dimensions of a main battery, *B*, (ground connections being made, of course), the relay at New York will transmit to Boston the message received from Cleveland. In such cases, the relay at New York becomes *a repeater*. Messages from New York to Chicago may thus be repeated at Meadville, Pa., without the intervention of any operator.

446. Duplex and Quadruplex Telegraphy.—The simple Morse system, just described, is very reliable, but a given wire can transmit only one message at a time. By what is known as the *duplex system*, a wire may be made to convey two messages, *one each way, at the same time*, without conflict. By what is known as the *quadruplex system*, a wire may be made to carry four messages, *two each way, at the same time.* Delany's *multiplex system* enables the sending of six messages in the same direction at one time. The student is referred to technical works on telegraphy for an explanation of these systems. A good Morse operator can send or receive thirty or forty words a minute; by the aid of a combination of recent inventions, fifteen hundred words have been transmitted over a single wire in one minute.

447. Electric Bells.—The construction of the trembler or electric bell will be clearly seen by an examination of Fig. 232. When the button at *P* (anywhere on the circuit) is pushed, two metal pieces are brought into contact and the circuit is thus completed. The spring carried by the armature of the magnet, *E*, makes contact with the tip of the screw at *C*, except when it is drawn away by the attraction of the magnet.

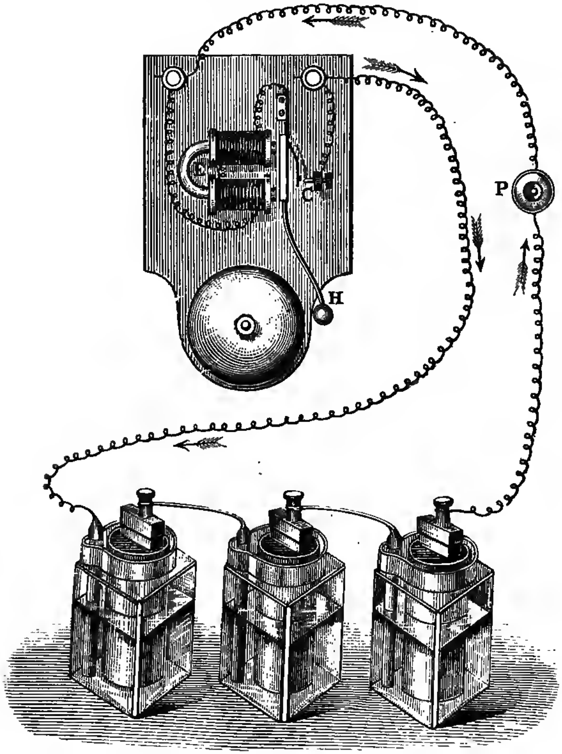


FIG. 232.

(*a.*) When the spring rests against the end of the screw at *C* (the circuit being closed at *P*), the cores of *E* are magnetized. They then draw the armature away from the end of the screw and break the circuit at *C*. *E*, being thus demagnetized, no longer attracts its armature, which is thrown back against the end of the screw by the elasticity of the spring that supports it. It is then again attracted and released, thus vibrating rapidly and striking a blow upon the bell at *H* at every vibration. (See § 459, *a.*)

448. Making Permanent Magnets.—A common way of magnetizing a steel bar is to draw one end of a strong magnet from one end of the bar to the other, repeating the operation several times, *always in the same direction.* A second method is to bring together the opposite poles of two magnets at the middle of the bar to be magnetized and simultaneously drawing them in opposite directions from the middle to the ends. A steel bar may be magnetized by striking it on end with a wooden mallet while it is held in the direction assumed by the dipping needle. If a bar of steel be heated to redness and cooled, either slowly or suddenly, while lying in the magnetic meridian, it acquires magnetic polarity. But better than any of these can give are the effects produced by electro-magnetism.

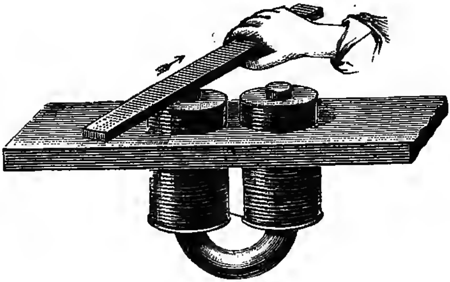


FIG. 233.

The bar may be permanently magnetized by drawing it, from its centre, in one direction over one pole of a powerful electro-magnet and then, from its centre, in the opposite direction over the other pole and repeating the process a few times (Fig. 233).

A bar of steel placed within a helix through which a strong current is passing will be permanently magnetized. The bar should be passed into one end of the helix and removed from the other end.

(*a.*) A long, thin, steel magnet is more powerful in proportion to its weight than a thicker one is. Compound magnets are, therefore, made of thin pieces of steel, separately magnetized and then bound together in bundles. A horse-shoe magnet will lift a load three or four times as heavy as will a bar magnet of the same weight. The lifting power is increased if the area of contact between the poles and the armature is increased. The lifting power of a magnet is strengthened, in an unexplained way, by gradually increasing the load on its armature day by day until it bears a load which at the outset it could not have borne. If the load be so increased that the armature is torn off, the power of the magnet falls at once to its original value. The attraction between a powerful electro-magnet and its armature may amount to 200 lb. *per* square inch, or 14,000 *g. per sq. cm.* Small magnets lift a greater load in proportion to their own weight than large ones. A good steel horse-shoe magnet weighing one pound ought to lift twenty pounds' weight. A steel magnet loses part of its magnetism by being jarred or knocked about and all of it by being heated to redness.

449. Armatures.—Magnets left to themselves soon lose their magnetism. They should, therefore, be provided with armatures. *Armatures are pieces of soft iron placed in contact with opposite poles,* as shown in Fig. 234. The two poles of the magnet (or magnets, for two bar magnets may be thus protected) act inductively upon the armature and produce in it poles opposite in kind to those with which they come in contact. The poles of the armature in turn react upon the magnet and, by their power of attraction, aid in retaining the magnetism.

FIG. 234.

450. Magnetic Units.—All magnetic quantities, strength of poles, intensity of magnetization, etc., are expressed in terms of special units derived from the fundamental units of *length, mass* and *time, i.e.,* they are C. G. S. units.

(*a.*) *Unit Strength of Magnetic Pole.*—The unit magnetic pole is one of such strength that it repels a similar pole of equal strength with a force of one dyne when it is placed at a distance of one centimeter from it.

(*b.*) *Magnetic Potential* being measured by *work* done in moving a unit magnetic pole against the magnetic forces, the unit of magnetic potential will be measured by the unit of work, the *erg*.

(*c.*) *Unit Difference of Magnetic Potential* exists between two points when it requires the expenditure of one *erg* of work to bring a — unit magnetic pole from one point to the other against the magnetic forces.

(*d.*) *Intensity of Magnetic Field* is measured by the *force* it exerts upon a unit magnetic pole; hence,

(*e.*) *Unit Intensity of Field* is that which acts on a unit — pole with a force of one dyne.

451. Electro-Magnetic Units.—The magnetic units just described give rise to a set of electrical units, in which *the strength of currents, etc., are expressed in magnetic measures.* (See § 320.)

(*a.*) *Unit Strength of Current.*—A current has unit strength when 1 *cm.* length of its circuit bent into an arc of 1 *cm.* radius (so as to be always 1 *cm.* away from the magnet-pole) exerts a force of one dyne on a unit magnet-pole placed at the centre.

(*b.*) *Unit of Quantity of Electricity* is that quantity which is conveyed by unit current in one second.

(*c.*) *Unit of Difference of Potential* (or of E. M. F.) is that which exists between two points when it requires the expenditure of one *erg* of work to bring a unit of + electricity from one point to the other against the electric force.

(*d.*) *Unit of Resistance.*—A conductor possesses unit resistance when unit difference of potential between its ends causes a current of unit strength to flow through it.

452. Practical Units.—As some of these "absolute" electro-magnetic units are too large for common, convenient use and others are too small, the practical units, the volt, the ohm, the ampere and the coulomb have been chosen and are generally used. These units have been already described, the value of each in absolute electro-magnetic units being given.

453. Molecular Changes in a Magnet.—When a steel or iron bar is strongly magnetized, it increases in length and diminishes in thickness. This effect is probably due to the magnetization of the individual molecules, which tend to set themselves parallel to the length of the bar. This supposition is confirmed by the observation that at the moment when a bar is magnetized or demagnetized, a faint metallic click is heard in the bar. When a tube containing water rendered muddy with finely divided magnetic oxide of iron is magnetized, the liquid becomes clearer in the direction of magnetization, the particles apparently setting themselves end to end and allowing more light to pass between them. A piece of iron, when powerfully magnetized and demagnetized in rapid succession, grows hot, as if the changes were accompanied by internal friction.

454. Theory of Magnetism.—These and other phenomena point to a theory of magnetism very different from the old notion of "magnetic fluids." It appears that every molecule of a magnet is itself a magnet and that the molar magnet becomes a magnet only by the molecular magnets being turned so as to point one way. This conclusion is supported by the observation that if a glass tube full of iron filings be magnetized, the filings may be seen to set themselves endwise and that, when thus once set, *they act as a magnet until they are shaken up.*

455. Relation of Magnetism to Energy.—A magnet is a reservoir of potential energy. This energy is due to the expenditure, at some time, of a definite amount of energy, of some kind. By virtue of its potential energy, it can do a definite amount of work *and no more.* For instance, it may attract a certain amount of iron. When thus fully loaded, the magnet has done its full work and can do no more. *When the iron is torn from the magnet, more energy is expended and the magnet thus endowed again with potential energy. A magnet has not an inexhaustible supply of energy, as some have supposed.*

EXERCISES.

1. (*a.*) What is a magnetic pole? (*b.*) A magnetic equator? (*c.*) How does a magnet behave toward soft iron? (*d.*) How does soft iron behave toward a magnet?

2. (*a.*) State carefully the various effects that one magnet may exert upon a second magnet. (*b.*) Generalize these observed facts into a law.

3. On board an iron ship that is laying a submarine telegraph cable, there is a galvanometer used for testing the continuity of the cable. It is necessary to prevent the magnetized needle of the galvanometer from being affected by the magnetism of the ship. How can this be done?

4. (*a.*) Given a bar magnet, how would you determine the sign of either of its poles? (*b.*) What is a diamagnetic substance?

5. If a magnetic needle be freely suspended from its centre of gravity, what position will it assume?

6. (*a.*) Do you think that the earth is a magnet? (*b.*) Give a good reason for your answer. (*c.*) Do the magnetic and the geographical meridians ever coincide? (*d.*) Do they always coincide? (*e.*) If they do not coincide, what name would you give to their difference in direction?

7. (*a.*) Does the magnetic attraction of the earth upon a ship's compass *tend* to float the ship northward? (*b.*) If so, why? If not, why not?

8. (*a.*) State and illustrate the second law of motion. (*b.*) State and illustrate the law of universal gravitation. (*c.*) A body falls to the ground from rest in 11 seconds; what is the space passed over?

9. An electric bell in Cleveland, Ohio, is to be rung by a battery in New York City. Should the magnet coils of the bell be made of fine or coarse wire?

10. Would you use a long coil or a short coil galvanometer to measure the current used to ring the bell above mentioned?

11. Would it make any difference whether the galvanometer were put into the circuit at New York or at Cleveland if the line be thoroughly insulated?

12. With a local battery of 2 cells, each having an internal resistance of 2 ohms, what should be the resistance of the sounder?

13. The cells represented in Fig. 235 have each an E. M. F. of 2 volts and an internal resistance of 3 ohms. What is the resistance of the external circuit, *G*, if the battery is arranged in the best possible way? *Ans.* 2 ohms.

14. Why is it that when there is little other resistance in the circuit, a stout wire with few turns will make a stronger electro-magnet than a very fine wire with many more turns?

15. A battery of 5 Leclanché cells was connected in simple circuit with a galvanometer and a box of resistance coils. A deflection of 40° having been obtained by adjustment of the resistances, it was found that the introduction of 150 additional ohms of resistance brought down the deflection to 29°. A battery of ten Daniell's cells was then substituted in the circuit and adjusted until the resistance was 40° as before. But this time it was found that 216 ohms had to be added before the deflection was brought down to 29°. Taking the E. M. F. of a single Daniell's cell as 1.079 volt, calculate that of a single Leclanché cell. *Ans.* 1.499 volt.

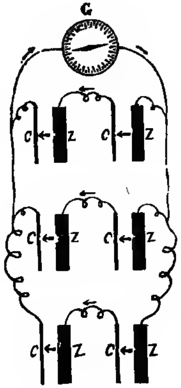


FIG. 235.

16. An electric bell has a resistance of 0.5 ohm. It requires a current of 20 milliamperes to ring it. It is on a line of 1 mile of No. 20 copper wire (see Appendix I). Ignoring the internal resistance of the battery, find how many Leclanché cells (*E. M. F.* = 1.5 volts) will be required.

17. We have to send a current through a telegraph line, 100 miles long, the resistance of which is 13 ohms *per* mile. The battery is composed of Daniell cells, each having an E. M. F. of 1.079 volts and an internal resistance of 2 ohms. The telegraphic instrument offers a resistance of 130 ohms and requires a current of 10 milliamperes to work it. Will one cell of battery answer our purpose? Why?

18. Under what circumstances will a magnet repel an unmagnetized piece of iron?

19. Give two or three differences between electric attractions and repulsions and magnetic attractions and repulsions.

20. A zinc and a copper plate are respectively united by copper wires to the terminals of a galvanometer. They are dipped, side by side, into a glass containing dilute sulphuric acid. The galvanometer needle, at first, shows a deflection of 28°, but five minutes later the deflection has fallen to 11°. How do you account for this falling off?

21. A wire, the resistance of which was to be determined, was placed in a Wheatstone's bridge, in which resistances of 10 and 100 ohms respectively were used as the fixed resistances. Its resistance was balanced when the adjustable coils were arranged to throw 281 ohms into circuit. What was its resistance? (See Appendix M, [*e*.].)
Ans. 25.1 ohms.

22. Relays are wound with long, fine wire and sounders with short, stout wire. Why is there this difference?

Recapitulation.—To be amplified by the pupil for review.

- MAGNETISM.
  - **MAGNETS.**
    - NATURAL.
    - ARTIFICIAL...
      - Permanent........
        - *Forms.*
        - *How Made.*
      - Temporary or Electro-Magnets.
        - *Definition.*
        - *Advantages.*
        - *Forms.*
        - *Residual Magnetism.*
        - *Telegraph.*
        - *Electric Bells.*
    - MOLECULAR..
      - Magnets.
      - Changes.
    - POLES.
    - CHARACTERISTICS.
    - LAWS.
    - RELATION TO
      - Magnetic .... *Substances.*
      - Diamagnetic. .. . *Substances.*
  - **RETENTIVITY.**
  - **THEORY.**
  - **MAGNETIZATION.**
    - BY CONTACT.
    - MODES OF.
    - BY INDUCTION.
      - Magnetic Field.
      - Lines of Force.
      - Precedes Attraction.
      - Magnetic Screens.
  - **TERRESTRIAL.....**
    - POLES.
    - MAGNETIC NEEDLES.
      - Compass.
      - Dipping.
      - Astatic.
    - DIP.
    - DECLINATION.
  - **MAGNETIC AND ELECTRO-MAGNETIC UNITS.**
  - **RELATION TO ENERGY.**

SECTION V.

INDUCED ELECTRICITY.

456. Induced Currents.—From our study of frictional electricity and magnetism, we are familiar with the term *induction,* by which we understand the influence that an electrified body exerts upon a neighboring unelectrified body or that a magnetized body exerts upon a neighboring magnetic but unmagnetized body. In 1831, Faraday discovered an analogous class of phenomena which we are now about to consider. *An induced current is a current produced in a conductor by the influence of a neighboring current or magnet.* A current used to produce such an effect is called an inducing current.

457. Inductive Effect of Closing or Breaking a Circuit.—In Fig. 236, *B* represents a double coil made as follows: On a hollow cylinder of wood or card-board are wound several layers of stout, insulated, copper wire. The two ends of this wire, which constitutes the *primary coil,* are seen dipping into the cups, *g g′*. Upon this coil and carefully insulated from it, is wound a much greater length of finer, insulated copper wire. The two ends of this wire, which constitutes the *secondary coil,* are seen connecting with a delicate, long coil galvanometer, *G*.

Remember that there is no electrical connection between the two coils. Wires from the poles of a voltaic cell, *P*, dip into mercury in the cups $g\ g'$, thus closing a circuit through the primary coil of *B*. While this circuit is closed, the galvanometer needle is at rest, showing that no current is passing through the secondary coil. By lifting one of the wires from its cup, the inducing current is interrupted. At this instant, the galvanometer needle is deflected, as by a sudden impulse that immediately passes away. This movement of the galvanometer needle shows the existence of a momentary, induced current in the secondary coil. The direction in which the needle turns, shows that the secondary current is direct, *i. e.*, that it has the same direction as the inducing current. If the wire just removed from the cup be replaced and the inducing current thus re-established, the galvanometer needle will be momentarily turned in the direction opposite to that in which it was previously turned. *When a current begins to flow through the primary coil, it induces a current in the secondary coil. When*

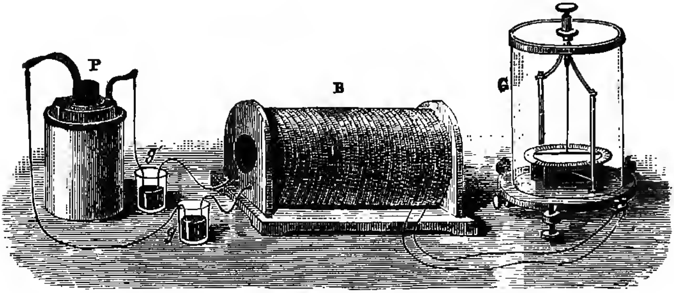


FIG. 236.

it ceases to flow through the primary coil, a current flowing in the opposite direction is induced in the secondary coil. Both induced currents are merely momentary in duration.

458. The Extra Current.—When a circuit is made or broken, each convolution of a coil placed in the circuit acts inductively upon the other convolutions of the coil as if they were portions of two unconnected circuits. *This action is called the induction of a current upon itself; the current thus produced is called the extra current.*

(*a.*) When the circuit is made, the extra current is inverse or opposite in direction to the primary current and acts against it. The extra current at the breaking of the circuit is direct and *adds its effect to that of the primary current.* Hence, a spark is more often seen on breaking than on making contact. Increasing the number of coils or convolutions in the circuit will increase the brilliancy of the spark. If the coil has an iron core (electro-magnet) the effect is especially marked.

459. Ruhmkorff's Coil.—The induction coil, often called, from the name of its inventor, *Ruhmkorff's coil, is a contrivance for producing induced currents in a secondary coil by closing and opening, in rapid succession, the circuit of a current in the primary coil.* The essential parts are described in § 457. In the complete instrument, the axis of the coils is a bundle of soft iron wires. These wires usually terminate in two small plates of soft iron which thus form the ends of the wire bundle. Around this bundle, is wound the primary coil of stout, insulated, copper wire. Upon the primary coil, but carefully insulated from it, is wound the secondary coil which is made of a great many turns of fine, silk covered, copper wire.

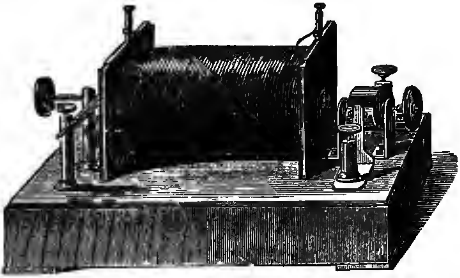


FIG. 237.

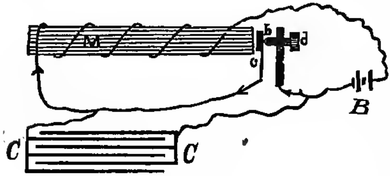


FIG. 238.

(*a.*) The wire bundle (*M*, Fig. 238) becomes magnetized by the action of the battery current in the primary coil and then adds its inductive effect upon the secondary coil to the effect of the primary itself. The primary circuit is rapidly broken and closed by an automatic interrupter or contact breaker, represented at the left hand of the coil, Fig. 237, and at the right hand of the diagram in Fig. 238. One of the posts there seen carries an elastic, metallic, vibrating plate with an iron hammer, *b*, at its end. This hammer vibrates back and forth between the end of the iron core of the coils and the end of the metal adjusting screw, *d*, which is carried by the other post seen in the figure. These posts are in the primary circuit. When the hammer rests against the end of the adjusting screw, the circuit is closed and the iron core is magnetized. As soon as the core is magnetized, it attracts the hammer, thus drawing it away from the end of the screw and breaking the circuit. As soon as the circuit is broken, the bar is demagnetized and the plate, by virtue of its elasticity, throws the hammer back against the screw, closing the circuit and again magnetizing the core. The plate is thus made to vibrate with great rapidity, each oscillation making or breaking the primary circuit and creating a series of induced currents in the secondary coil.

(*b.*) The *condenser* (*C C*, Fig. 238), which is generally placed in the pedestal or base of the coil, consists of a number of sheets of tinfoil insulated from each other by thin sheets of varnished paper or oiled silk. Alternate layers of the tinfoil are connected, *i. e.*, the first, third, fifth, seventh, *etc.*, layers are connected, as also are the second, fourth, sixth, eighth, *etc.*, thus forming two separate, insulated series. One series (*e. g.*, the odd numbered sheets) is connected with one of the posts of the contact breaker; the other series, with the other post. Thus, the plates of the condenser do not form a part of the primary circuit but are, as it were, lateral expansions of that circuit, one on each side of the contact breaker. The effect of the condenser is to lessen the spark when the primary circuit is made or broken and to increase the force of the discharge of the secondary coil.

(*c.*) For an ordinary Ruhmkorff's coil, one to three Bunsen or potassim di-chromate elements will suffice.

(*d.*) Most induction coils are provided with a *commutator*, for the purpose of changing the direction of the current through the primary coil and, consequently, the direction of the currents induced in the secondary coil. One form of the commutator is shown at the right hand end of Fig. 237. It is not an essential part of the instrument.

Experiment 104.—Let the members of the class join bare hands. Let the pupil at one end of the line place a finger on one of the binding posts or electrodes of the secondary coil of *a small* induction coil. Then let the pupil at the other end of the line, momentarily touch the other electrode. Each person in the line will feel a "shock." The experiment should not be tried with a powerful coil, as the spasmodic, muscular contractions thus produced are sometimes painful and permanently injurious.

460. Spark from the Induction Coil.—If the ends of the secondary coil be connected, opposite currents alternately traverse the connecting wire. When the ends are disconnected, the inverse current cannot overcome the resistance of the intervening air because of its low electromotive power (§ 458, *a*). *The direct current, produced by breaking the primary circuit, is alone able to force its way in the form of a spark.* The sparks vary with the power of the instrument.

(*a.*) Mr. Spottiswoode, of London, has made an induction coil, the secondary coil of which contains 280 miles of wire wound in 340,000 turns. This magnificent instrument has a resistance of more than

100,000 ohms, and, when worked with a battery of 30 Grove cells, yields a spark $42\frac{1}{8}$ inches long,—a result greater than that obtainable from any electric machine. The induction coil may be used to produce any of the effects of frictional electricity, it being at the same time nearly free from the limitations that atmospheric moisture places upon ordinary electric machines.

(*b.*) For many instructive and beautiful experiments with this instrument and other information relating thereto, see the little book, "Induction coils:—How made and how used," published by D. Van Nostrand, New York; Price, 50 cents.

461. Currents Induced by Change of Distance.—If the primary coil be made movable, as shown in Fig. 239, and, with a current passing through it, be suddenly placed within the secondary coil, the galvanometer will show that an inverse current is induced in the outer coil. When the needle has come to rest, let the primary coil be removed and the galvanometer will show that a direct current is induced. From this we see that *when the primary coil, bearing a current, is brought near or thrust into the secondary coil, an inverse current is induced in the latter; that when the coils are separated, a direct current is induced in the secondary coil; that the induced currents flow while a change of distance is varying the inductive effect of the primary current.* Removing the primary coil to an infinite distance is equivalent to breaking its circuit, as in § 457.

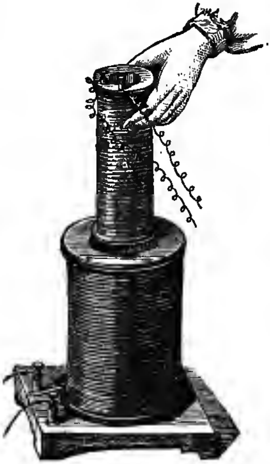


FIG. 239.

462. Magneto-Electric Currents. — We have already noticed that there is an intimate relation between electric and magnetic action. We have seen that an electric current may develop magnetism. Faraday found that electricity may be developed by magnets; the results of this discovery have already become of incalculable commercial importance. If, instead of the primary coil bearing the inducing current, a bar magnet be used, as shown in Fig. 240, the effects produced will be like those stated in the last paragraph. *When the magnet is thrust into the interior of the coil, an induced current will flow while the motion of the magnet continues. When the magnet becomes stationary, the current ceases to flow and the needle of the galvanometer gradually comes to rest. When the magnet is withdrawn, an induced current flows in the opposite direction.* Of course, it makes no difference whether the magnet be

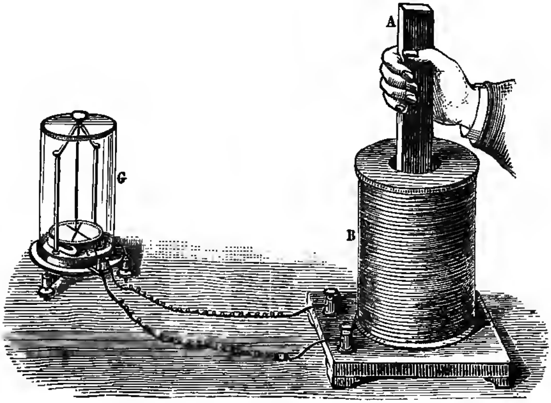


FIG. 240.

moved toward the coil or the coil be moved toward the magnet. The more rapid the motion, the greater will be the electromotive force of the induced currents.

463. The Inductive Action of a Temporary Magnet.—If within the coil, a soft iron bar (or still better, a bundle of straight, soft, iron wires) be placed, as shown in Fig. 241, the induced current may be more effectively produced by bringing one end of a permanent magnet near the end of the soft iron. In this case, the induced currents are due to the varying magnetism of the soft iron, this magnetism being due, in turn, to the inductive influence of the permanent magnet. Thus we see that *when the intensity of the magnetism of a bar of iron or steel is increased or diminished, currents are induced in the neighboring coil.* Similar effects may be produced by moving one pole of the magnet across the face of the coil from end to end.

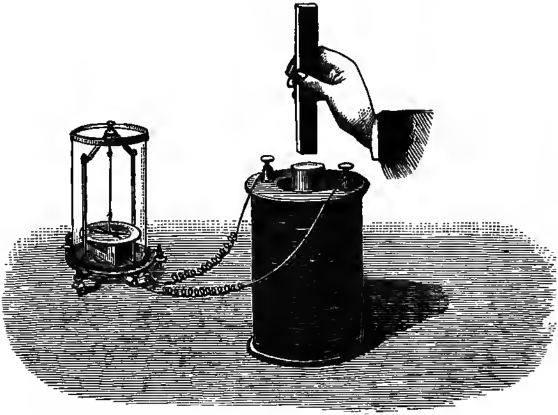


FIG. 241.

464. The Wheel Armature.—Imagine the soft iron bar in the helix of Fig. 241 to be grooved and several times as long as the helix through which it passes. Imagine the ends of this bar to be brought together so as to form a complete iron ring carrying one helix. If the number of helices upon the ring be increased to twelve we shall have the wheel armature, shown, in an unfinished condition, in Fig. 242. If the pole of a magnet be passed around the face of this wheel, it will pass twelve coils of wire and induce a current of electricity as it approaches each coil and an opposite current as it leaves each coil, thus inducing twenty-four currents for each revolution. Of course, it makes no difference whether the magnet be permanent or temporary, *whether the pole of the magnet moves by the coil or the coil passes by the pole of the magnet.* Then, if the magnet be fixed and the wheel turn upon its axis in such a way as to carry its coils across the end of the magnet, we shall be inducing twenty-four currents of electricity for each revolution of the wheel. This is what happens in the operation of a dynamo-electric machine. *When a closed circuit conductor moves in a magnetic field so as to cut across the lines of magnetic force* (§ 433), *an induced current of electricity flows through the conductor in one direction while the*

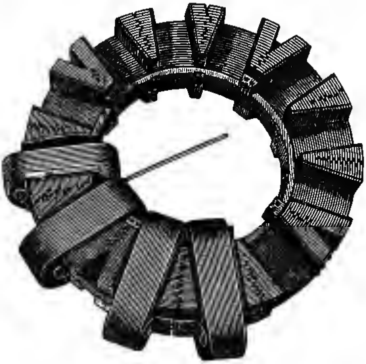


FIG. 242.

conductor is approaching the point of greatest magnetic intensity and in the opposite direction while the conductor is moving away from such point of maximum intensity. The varying magnetic intensity of the iron core of each moving coil increases this effect as explained in § 463. Of course, the number of coils on the armature may be more or less than twelve, or the armature may be of a form almost wholly different from that just described, but, in every case, the principle of its action is as above stated. The dynamo represented in Fig. 243 has only eight armature helices and diametrically opposite coils are joined so as to form four pairs.

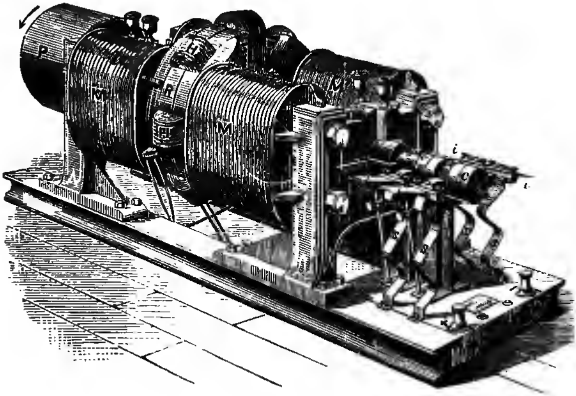


FIG. 243.

465. Dynamo-Electric Machines. — In the Brush dynamo-electric machine, represented in Fig. 243, a shaft runs through the machine from end to end, carrying a pulley, *P*, at one end, a commutator, *c*, at the other, and a wheel armature, *R*, at the middle. The armature, *R*, carries eight or more helices of insulated wire, *H H*.

As the shaft is turned by the belt acting upon P, R and c are turned with it. As R turns around, it carries the eight coils, H H, rapidly across the poles of the four powerful field magnets, M M.

As each coil passes each pole, it necessarily traverses the magnetic field and cuts across the lines of magnetic force; consequently, currents are induced in the coil. These currents are carried on insulated wires to the commutator rings, *c c*, where they are united in such a way as all to flow in the same direction, forming a continuous current. The electricity is taken from the revolving commutator, *c c*, by the four or more fixed, copper plates, *i i*, technically called "brushes," then carried down the flexible copper strips, *s s*, then passed through the insulated wire of the electro-magnets, *M M*, and, finally, to the + binding post. Thence the current passes by a wire to the external circuit, *e. g.*, to an arc lamp (Fig. 246) and from this to a second lamp, and so on through all of the lamps of the circuit and from the last lamp back to the — binding post of the dynamo-electric machine, thus making the circuit complete. Sixty or more arc lamps in series may be worked by one of these machines. No part of the circuit of a dynamo should have an earth connection. The complete circuit (except through the lamp carbons) should be of carefully insulated wire.

Dynamo-electric machines are being rapidly introduced for purposes of electric lighting, electro-plating, motive power, telegraphy, *etc.* They are made in various forms, but the principle underlying the action of them all is the same as that stated in the last paragraph. After mastering the action of one dynamo-electric machine the pupil will have little trouble in understanding the action of any other that he may have a chance to examine. Dynamo-electric machines are often called "dynamos." A small, hand power dynamo, suitable for school use, may be had for $30 or more.

(*a.*) In cases where a high E. M. F. is needed (as in arc electric lighting), the armature helices are wound with many turns of wire which gives a high internal resistance. Compare § 399. When a smaller E. M. F. is wanted (as in direct, incandescence electric lighting or in electro-plating), fewer turns of wire of greater diameter are used. This reduces the internal resistance of the dynamo. Compare § 400. The E. M. F. will vary with the strength of the magnetic field and the speed at which the armature is revolved. Thus, a given dynamo may be run slowly for a few lamps and at a higher speed for a greater number of lamps. In practice, however, special automatic devices are generally provided for adapting the E. M. F. to the varying resistances of the external circuit without changing the speed of the dynamo.

(*b.*) If permanent magnets are used instead of electro-magnets, the machine is called a *magneto-electric* instead of a dynamo-electric machine. Small magnetos (armatures wound with long, thin wires) are much used for electro-medical purposes. The patient holds two metallic handles connected with the terminals of the instrument and receives a rapid succession of shocks when the armature is turned.

(*c.*) If, instead of expending mechanical energy to turn the shaft of the dynamo and thus produce an electric current, we pass a strong current of electricity through the dynamo, the shaft of the dynamo will be turned in the opposite direction and may be made to drive ordinary machinery as an *electric motor.* In the former case, we convert mechanical energy into electric energy ; in the latter case, we convert electric energy into mechanical energy (§ 473).

466. Incandescence Electric Lamps.—When a conductor of high resistance is heated to incandescence by the passage of a current, we have an illustration of the fundamental principle of incandescence electric lighting. To prevent the fusion of the conductor, a carbon filament, about the size of a horse-hair, is used—carbon never having been melted. To prevent the combustion of the carbon filament, it is enclosed in a glass globe containing either a high vacuum or only some inert gas, incapable of acting chemically upon the carbon at even the high temperature to which it is to be subjected. The ends of the carbon are connected with platinum wires that are fused into and passed through the glass.

THE SWAN ELECTRIC LAMP.

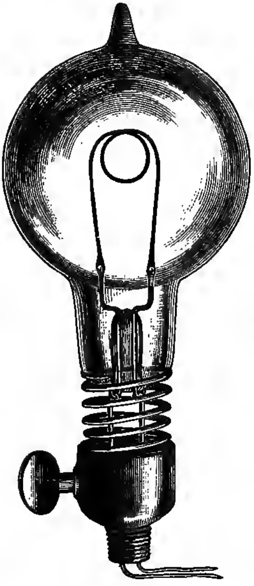


FIG. 244.

(*a.*) The filament is carbonized in different ways and given different shapes by different inventors. The Edison carbon is made of bamboo fibre and is in the shape of an ordinary hair pin. The Swan carbon is made of parchmentized cotton thread. Fig. 244 represents the Swan incandescence lamp and is half the actual size of the standard sixteen candle power lamp. Incandescence lamps are generally operated abreast, as shown in Fig. 245, being placed, as it were, in little bridges of wire connecting the two conductor "mains." Thus, *the resistance of the circuit is reduced by the successive addition of lamps.*

(*b.*) The resistance of carbon is lowered by heating the conductor. The "hot" resistance of an incandescence lamp is about $\frac{2}{3}$ its "cold" resistance.

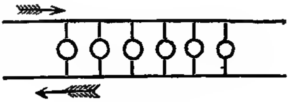


FIG. 245.

467. The Voltaic Arc.—

The most brilliant luminous effect of current electricity is the arc of an electric lamp. This lamp consists essentially of two pointed bars of hard carbon, generally copper coated

(Experiment 78), placed end to end in the circuit of a powerful current. If the ends of the carbons be separated a short distance while the current is passing, the carbon points become intensely heated and the current will not be interrupted thereby. *When the carbons are thus separated, their tips glow with a brilliancy which exceeds that of any other light under human control, while the temperature of the intervening arc is unequalled by any other source of artificial heat.*

THE BRUSH ELECTRIC LAMP.

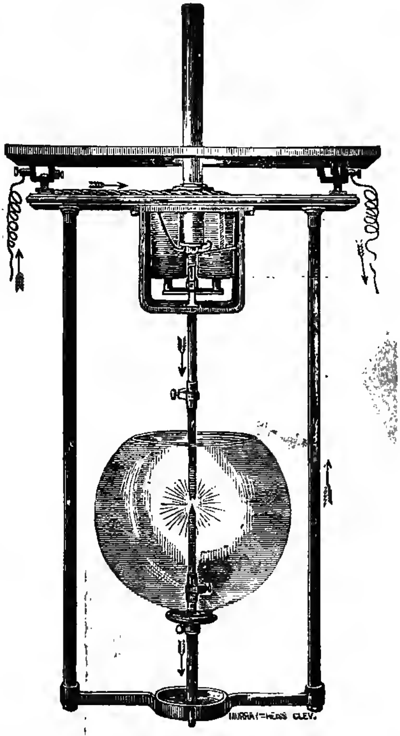


FIG. 246.

The mechanism shown in the upper part of Fig. 246, is for the purpose of automatically separating the carbons and "feeding" them together as they are burned away at their tips and for the purpose of cutting the lamp out of the circuit in case of any irregularity or accident. Such lamps of from one to two thousand candle power and requiring an expenditure, at the dynamo, of about one-horse power *per* lamp are now quite common. Lamps of a hundred thousand candle power have been made. The current may be furnished by a battery of forty or more Grove's cells but, for economical reasons, it is almost universally supplied by a dynamo-electric machine.

(*a.*) It is necessary to bring the carbons into contact to start the light. The tips of the carbons become intensely heated on account of their small area of contact and the consequent high resistance at that point. The carbon (and its usual copper coating) begins to volatilize. When the carbons are separated, the current is kept up by this intervening layer of vapor and the accompanying disintegrated matter, which act as a conductor. Arc lamps are generally operated in series, so that the current passes in succession through all the lamps on the circuit. *The resistance of the circuit is thus increased by the successive addition of lamps.*

FIG. 247.

(*b.*) The constitution of the voltaic arc may be studied by projecting its image on a screen with a lens. Three parts will be noticed:

1. The dazzling white, concave extremity of the positive carbon.
2. The less brilliant and more pointed tip of the negative carbon.
3. The globe shaped and beautifully colored aureole surrounding the whole.

(*c.*) There is a transfer of matter across the arc in the direction of the current, the positive carbon wasting away more than twice as rapidly as the negative. Most of the light of the lamp is radiated from the crater at the end of the positive carbon. If the arc be too short, many of these rays will be intercepted by the negative (generally the lower) carbon, thus lessening the efficiency of the lamp. If the arc become too long, it will "flame" and much of the light thus be lost. If the electrodes be horizontal, the arc will be curved upward by ascending air currents. Arc lamps are now largely used for lighting streets, factories, stores, etc., many thousands having been sold in every quarter of the globe (§ 000).

468. The Telephonic Current.—An electric current may be induced in a coil of insulated wire surrounding a bar magnet by the approach and withdrawal of a disc of soft iron. The disc, *a* (Fig. 248), is magnetized by the inductive influence of the magnet, *m*, (§ 435). The disc, thus magnetized, reacts upon the magnet, *m*, and changes the distribution of magnetism therein. By varying the distance between *a* and *m*, the successive changes in the distribution of the magnetism of *m* induce to-and-fro currents in the surrounding coil (§ 463). When *a* approaches *m*, a current flows in one direction; when it recedes, the current flows in the opposite direction.

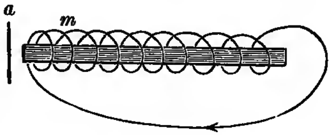


FIG. 248.

469. The Telephonic Circuit.—If the wire surrounding the magnet mentioned in the last paragraph be continued to a distance and then wound around a second bar magnet, as shown in Fig. 249, the currents induced at *M* would affect the magnetism of the bar at *M'* or the intensity of its attraction for the neighboring disc, *a'*. A vibratory motion in the disc, *a*, would induce electric currents at *M*; these currents, when transmitted to *M'*, perhaps several miles distant, would affect the magnetism of the bar there and tend to produce exactly similar vibrations in *a'*. "It is as if the close approach and quick oscillation of the piece of soft iron fretted or tantalized the magnet and sent a series of electrical shudders through the iron nerve." When the current generated at *M* flows in such a direction as to reinforce the magnet at *M'*, the latter attracts *a'* more strongly than it did before. When the current flows in the opposite direction, it weakens the magnetism of *M'*, which then attracts *a'* less. The disc, therefore, flies back. Thus, the vibrations of *a'* are like those of *a*.

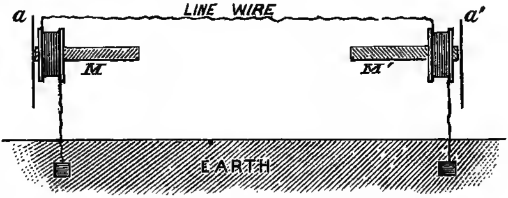


FIG. 249.

(*a*.) We have here the principle of the telephone, so far as electric action is involved. Further consideration of this instrument must be deferred until we have learned more concerning sound. (See § 505)

EXERCISES.

1. A dynamo is feeding 16 arc lamps, the average resistance of each of which is 4.56 ohms. The internal resistance of the dynamo (*i.e.*, of the wire conductors of the armature and field magnets) is 10.55 ohms. What current does the dynamo yield?

Ans. 10.04 amperes.

2. If a wire about 18 inches long be attached to one electrode of a potassium dichromate cell and the other electrode momentarily touched with the other end of the wire, a minute spark may be noticed at the instant of breaking the circuit. If the wire be bent into a scalariform or ladder like shape and the experiment repeated, the spark will be greater than before. If the form of the external circuit be again changed by winding the wire into a spiral (as shown in Fig. 250), the spark will be still greater. Explain the repeated increase in the spark.

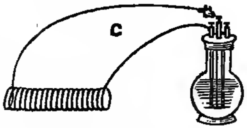


FIG. 250.

3. A dynamo is run at 450 revolutions, developing a current of 9.925 amperes. This current deflects the needle of a tangent galvanometer, 60°. (See Appendix L.) When the speed of the dynamo is sufficiently increased, the galvanometer shows a deflection of 74°. What is the current developed at the higher speed?

Ans. 20 amperes.

4. The current running through the carbon filament of an incandescence lamp was found to be 1 ampere. The difference of potential between the two terminals of the lamp was found to be 30 volts. What was the resistance of the lamp?

5. A yard of silver wire weighs 7.2 grains and has a resistance of 0.3 ohm. What is the resistance of a foot of silver wire that weighs one grain? *Ans.* 0.24 ohm.

6. If a pure copper wire has a weight of one grain and a resistance of 0.2106 ohms per foot and a commercial copper wire has a weight of 164 grains and a resistance of 0.547 ohms per 20 ft., what is the percentage conductivity of the latter as compared with pure copper?

Ans. 93.9 per cent.

7. I want to place, in series, 10 incandescence lamps, each of 25 ohms resistance; the line wire is to be 200 feet long and must have not more than 2 per cent. of the resistance of the lamps. Determine from the table in Appendix I what size of wire (American gauge) should be used. *Ans.* No. 24.

8. I want to place the same lamps abreast. The line wire is to be 200 feet long and have a resistance of not more than 2 per cent. that of the lamps. Determine from the table what size wire should be used. *Ans.* No. 4 (B. & S.)

9. What length of No. 0000 pure copper wire (B. & S.) will have a resistance of 1 ohm? (See Appendix I.) *Ans.* 19607.84 ft.

10. A dynamo has an E. M. F. of 206 volts and an internal (or interpolar) resistance of 1.6 ohms. Find the current strength when the external resistance is 25.4 ohms. *Ans.* 7.6 amperes.

11. A dynamo has an internal resistance of 2.8 ohms. The line wire has a resistance of 1.1 ohms and joins the dynamo to 3 arc lamps in series, each lamp having a resistance 3.12 ohms. Under such conditions, the dynamo develops a current of 14.8 amperes. What is the E. M. F.? *Ans.* 196.25 volts.

12. A dynamo, run at a certain speed, gives an E. M. F. of 200 volts. It has an internal resistance of 0.5 ohm. In the external circuit are 3 arc lamps in series, each having a resistance of 2.5 ohms. The line wire has a resistance of 0.5 ohm. I want a current of just 25 amperes. Must I increase or lessen the speed of dynamo?

13. With an external resistance of 1.14 ohms, a dynamo develops a current of 81.58 volts and 29.67 amperes. What is the internal resistance of the dynamo? *Ans.* 1.61 ohms.

14. Upon trial, it was found that a dynamo that was known to have an internal resistance of 4.58 ohms developed a current of 157.5 volts and 17.5 amperes. What was the resistance of the external circuit? *Ans.* 4.42 ohms.

15. Three incandescence lamps having a resistance of 39.3 ohms each (when hot) were placed in series. The total resistance of the circuit outside of the lamps was 11.2 ohms. The current measured 1.2 amperes. What was the E. M. F.? *Ans.* 154.92 volts.

16. The same lamps were placed in multiple arc with another dynamo. The line wire was adjusted so that its resistance with the internal resistance of the machine was 11.2 ohms as before. The current was 1.2 amperes. What was the E. M. F.?

Ans. 29.16 volts.

17. A dynamo supplies current for two incandescence lamps in series, each having a hot resistance of 97 ohms. The other resistances of the circuit amounted to 12 ohms. The current in the first lamp was 1 ampere. What was the current carried by the carbon filament of the second lamp? What was the E. M. F.?

18. The resistance of the normal arc of an electric lamp is 3.8 ohms. The current strength is 10 amperes. What is the difference of potential between the carbon tips. *Ans.* 38 volts.

19. The resistance of the arc lamp above mentioned, when the carbons are held together, is 0.62 ohm. When it is burning with normal arc and a 10 ampere current, what is the difference of potential between the terminals of the lamp? *Ans.* 44.2 volts.

HONORARY PROBLEMS.

20. Four arc lamps, with a resistance of 6 ohms each, are joined in series, 150 feet apart. The first lamp is 1,500 feet and the last is 1,350 feet from the dynamo. The line wire has a conductivity of 96 per cent. that of pure copper. Its resistance must not exceed 8 per cent. of that of the lamps. The resistance of a foot of pure copper wire 1 mil in diameter being 9.94 ohms, what must be the diameter of the line wire? *Ans.* 133 mils or 0.133 inch.

Use No. 10 wire, B. W. G. (App. 1).

21. Twenty-five similar voltaic cells having an internal resistance of 15 ohms each were joined in series, by short and stout copper wires to a 70 ohms incandescence lamp and produced a current of 0.112 ampere. What would be the strength of the current sent by a series of 30 such cells through a series of 2 lamps, each of 30 ohms resistance? *Ans.* 0.118 ampere.

22. What would have been the strength of current through the two lamps if the area of each of the battery plates had been doubled, all things else remaining the same? *Ans.* 0.215 ampere.

23. I join 50 arc lamps in series. Each lamp has a resistance of 4.5 ohms. The line wire connecting them with the dynamo is $3\frac{1}{2}$ miles long and its conductivity is 90 per cent. that of pure copper. One tenth of the total energy of the external circuit is lost in heating this line wire. What is its diameter, it being assumed that 1 foot of pure copper wire. 1 mil in diameter has a resistance of 9.94 ohms.

Ans. 90.3 mils.

Use No. 11 wire (B. & S.)

Recapitulation.—To be amplified by the pupil for review.

HIGH POTENTIAL ELECTRICITY INDUCED BY

- **CLOSING.**
- **BREAKING.**
  - PRIMARY CIRCUIT.
    - Primary.
    - Secondary.
    - Ruhmkorff.
      - *Coils.*
    - Extra Current.
- **CHANGE OF DISTANCE OF PRIMARY CIRCUIT.**
- **MAGNETS.**
  - PERMANENT.
    - Telephones.
      - *Current.*
      - *Circuit.*
    - Magneto-Electric Machines.
  - TEMPORARY.
    - Wheel Armature.
    - Dynamo-Electric Machines, Used for....
      - *Electro-Plating.*
      - *Incandescence Electric Lighting.*
      - *Arc Electric Lighting.*
      - *Charging Storage Batteries.*
      - *Motive Power.*
    - Electric Motors.

SECTION VI.

ELECTRIC CURRENTS AS RELATED TO HEAT AND MECHANICAL WORK.

470. The Convertibility of Electric Energy.—Whenever an electric current does work of any kind, it does it at the expense of a part of its own energy. Anything that increases the resistance of a circuit, decreases the strength of the current (§ 386). But such a diminution may be caused by a counter electromotive force set up somewhere in the circuit. The E. M. F. of polarization is an example of the truth under consideration. Whenever a current is used to drive an electric motor, the action of the motor generates a back current that diminishes the current of the battery or dynamo. *All of the current that is not expended in some such way, in external work, is dissipated as heat.* The dissipation may be in the battery (or dynamo), in the external circuit or in both. The heat will appear wherever there is resistance. If the poles of a battery or dynamo be short circuited, most of the heat will be developed in the battery or dynamo. If the external circuit be a thin wire of high resistance, it will grow hot while the generator will remain comparatively cool.

471. Joule's Law.—The quantity of heat developed in a conductor by the passage of an electric current is proportional:—

(1.) To the resistance of the conductor.

(2.) To the square of the strength of the current.

(3.) To the time the current is flowing.

A current of one ampere flowing through a resistance of one ohm, develops therein, *per* second, a quantity of heat which (or its mechanical equivalent) is called a *joule.* It is equal to 0.7373 of a foot-pound or to 0.24 of a lesser calorie (§ 579). A lesser calorie is, therefore, equal to 4.17 joules.

These facts are concisely stated by the following equation, known as Joule's Law:—

$$H = C^2Rt \times 0.24,$$

in which H represents the number of lesser calories; C, the number of amperes; R, the number of ohms and t, the number of seconds. In other words, *a current of one ampere flowing through a resistance of one ohm develops therein 0.24 of a lesser calorie per second.*

$$\text{Foot-pounds} = C^2Rt \times 0.737335.$$

(*a.*) In investigating this subject, Joule used instruments on the principle indicated in Fig. 251, in which a thin wire joined to two stout conductors is enclosed within a glass vessel containing alcohol, into which a thermometer dips. The resistance of the wire being known, its relation to the other resistances may be calculated.

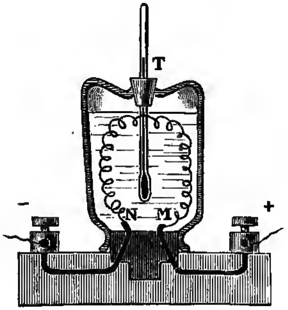


FIG. 251.

Experiment 105.—Send the current from a few cells through a chain made of alternate links of silver and platinum wires. The platinum links grow red-hot while the silver links remain comparatively cool. The explanation is that the specific resistance (Appendix K, [2]) of platinum is about six times that of silver and that its specific heat is about twice as great; hence the rise of temperature in wires of equal thickness traversed by the same current is about twelve times as great for platinum as for silver.

472. Heating Wires by the Current. — The resistance of metals increases with the temperature. Consequently, a thin wire heated by the current will resist more and more and grow hotter and hotter until it loses heat by conduction and radiation into the surrounding air as rapidly as heat is supplied by the current. *Thin wires heat much more rapidly than thick. The rise of temperature in different parts of a wire of uniform material but varying diameter (the current remaining the same) will be inversely proportional to the fourth power of the diameters.*

(*a.*) Suppose a wire at any point to become reduced to *half* its diameter. The cross-section will have an area $\frac{1}{4}$ as great as in the thicker part. The resistance here will be 4 times as great, and the number of heat units developed will be 4 times as great as in an equal length of the thicker wire. But 4 times the amount of heat spent on $\frac{1}{4}$ the amount of metal will warm it to a degree 16 times as great ($16 = 2^4$).

(*b.*) A thin platinum wire, heated white-hot by a current, is sometimes used in surgery, instead of a knife, as it sears the ends of the severed blood vessels and thus prevents hemorrhage. Platinum is chosen on account of its infusibility, but even platinum wires are fused by too strong a current. Carbon is the only conductor that resists all attempts at fusion (§ 466).

(*c.*) Sometimes stout conducting wires are laid from a battery at a safe distance to a fuse connected with a blast of powder or other explosive. In the fuse, is a thin platinum wire, forming part of the electric circuit. The fuse is ignited by heating the platinum wire by sending the current through it. Such methods are frequently used in the operations of both peace and war.

473. Electric Motors.—*An electric motor is a device for converting the energy of an electric current into motive power by means of electro-magnets.* Illustrative apparatus of this kind may be found in many school laboratories or will be gladly supplied by dealers in philosophical apparatus. But the best electric motors are the now common dynamo electric machines or slight modifications thereof. Such "electro-magnetic engines" are rapidly coming into use for operating sewing machines and other light machinery, the current being supplied indirectly by a storage battery or directly by a voltaic battery or dynamo. Some "Electric Light and Power Companies" now run such motors on their arc light circuits, selling current to some for power and to others for light. In many cases where it is undesirable to use a steam engine, an electric motor may be made available. Such motors, up to the capacity of 40 H. P., are now in the market. Some of them have been successfully and economically used in propelling street railway cars.

474. Electric Transmission of Power.—A water fall, perhaps at a point not easily accessible, may be made to turn a turbine or other water wheel, which shall drive a dynamo, which shall generate a current, which shall be carried by wire to some available point and there converted into mechanical power again by means of an electric motor. Thus, an otherwise waste water-power may be made a source of profit. The scheme of thus distributing part of the power of Niagara over the State of New York has been seriously considered. It may be possible (as a profitable commercial undertaking) to burn cheap fuel *at the coal mine* for running large stationary engines and thus deliver the power to consumers at great distances.

475. The Watt.—The electric unit of power (rate of doing work) is called a watt. *A watt is the amount of power conveyed by a current of one ampere through a difference of potential of one volt.* It equals ($10^{-1} \times 10^8 =$) 10^7 ergs or $\frac{1}{746}$ horse-power,

$$W = C \times E = \frac{E^2}{R} = C^2 R,$$

in which W equals the number of watts; C, the number of amperes; E, the number of volts and R, the number of ohms.

For example, if the difference of potential (Appendix M, [4 *a*.]) between the terminals of an arc lamp that is supplied with a ten ampere current be 45.8 volts, how much of the power used in driving the dynamo is consumed in the lamp?

$W = C \times E = 10 \times 45.8 = 458$, the number of watts.
$458 \div 746 = 0.614$, the number of horse-powers.

(*a*.) The formula $W = C \times E$ is determined by the definition of the watt. From Ohm's law, we see that $C = \frac{E}{R}$. Substituting this value of C, the formula becomes $W = \frac{E}{R} \times E = \frac{E^2}{R}$, as above. This shows that *the power varies as the square of the E. M. F. when the resistance remains constant,* or that *the power varies inversely as the resistance when the E. M. F. remains constant.*

(*b*.) $W = C \times E$. But $E = C R$. Substituting this value of E, the formula becomes $W = C \times C R = C^2 R$, as above. This shows that *the power varies as the square of the current when the resistance remains constant* or that *the power varies as the resistance when the current remains constant.*

476. Relation of Conductors to E. M. F.—This subject may be well studied by means of an example. The energy of a ten ampere current with an E. M. F. of fifty volts is equal to that of a five ampere current with an E. M. F. of one hundred volts.

$$W = C \times E = 10 \times 50 = 100 \times 5 = 500.$$

These equivalent currents (500 watts each), flowing through similar wires, will develop widely different quantities of heat. If we take any convenient wire, say one of fifteen ohms, the heat developed in each case will be as follows:

$$H = C^2 \times Rt \times 0.24. \quad (\S\ 471.)$$

$10^2 \times 15 \times 0.24 = 360$, the number of heat units *per* second.
$5^2 \times 15 \times 0.24 = 90$, " " " "

In other words, the same electric energy develops only one-fourth as much heat with the current of high electromotive force as it does with the current of low E. M. F., the same wire being used. It is easily evident that a great saving in the cost of conductors may be made possible by the use of currents of high E. M. F. (See § 474.) But such currents are more dangerous to handle and require careful insulation and special precautions to lessen the risk of serious accident.

EXERCISES.

1. What shorter name may be given for a volt-ampere?

2. What electrical horse-power is required to send a current of 10 amperes through 10 arc lamps (in series) each having a resistance of 4.476 ohms? *Ans.* 6 H. P.

3. How many joules will be developed per minute by a 10 ampere current in a lamp of 4.42 ohms resistance? *Ans.* 26520 joules.

4. How many calories will be developed in a 40 ohm incandescence lamp by the passage of a current of 1.2 amperes through it for a minute? *Ans.* 82.944 calories.

5. Find the mechanical equivalent (in foot-pounds) of the work done by a 5 ampere current working for a minute against 100 ohms resistance? *Ans.* 110600¼ foot-pounds.

6. A 30,000 watt dynamo develops an E. M. F. of 3000 volts. What is the current strength? *Ans.* 10 amperes.

7. One coulomb of electricity, in passing from *A* to *B*, does one joule of work. What is the difference of potential between *A* and *B*?

8. The difference of potential between the two terminals of an arc lamp was found to be 37.7 volts. A 25 ampere current was passing through the lamp. What is the power consumed in the lamp? *Ans.* 942.5 watts, or 1¼ H. P.

9. A certain Edison incandescence lamp has a resistance of 125 ohms. The difference of potential between the terminals of the carbon is 110 volts. (*a.*) What is the current strength? (*b.*) What amount of heat is developed in the lamp *per* second?

Ans. (*a.*) 0.88 ampere; (*b.*) 23.23 lesser calories.

10. A Grove cell has an E. M. F. of 1.9 volts and a resistance of 0.4 ohm. Its plates are joined, first, by a 3 ohms wire; second, by a 30 ohms wire. (*a.*) What is the current in each case? (*b.*) What amount of heat is developed in the cell in each case?

Ans.
(*a.*) .559 amperes in first case.
.0625 " " second case.
(*b.*) .125 joules " first case.
.00625 " " second case.
About 80 times as much.

Recapitulation.—To be amplified by the pupil for review.

ELECTRIC ENERGY AS RELATED TO

- **HEAT ENERGY**.........
  - DISSIPATED
  - JOULE'S LAW.
  - EFFECT ON WIRES.
  - RELATION OF CONDUCTORS TO E. M. F.
- **MECHANICAL ENERGY.**
  - ELECTRIC MOTORS.
  - TRANSMISSION OF POWER.
  - THE WATT.
  - ELECTRICAL H. P.

REVIEW QUESTIONS AND EXERCISES.

1. (*a.*) Give the laws for pressure of liquids and (*b.*) explain each by some fact or experiment.

2. (*a.*) What is a natural magnet? (*b.*) An artificial magnet? (*c.*) How does a magnet behave toward soft iron? (*d.*) How does one magnet behave toward another magnet?

3. Give the facts in regard to the variation of the magnetic needle.

4. (*a.*) What are conductors in electricity? (*b.*) In what ways may electrical separation be effected?

5. (*a.*) What conditions in the construction and erection of lightning-rods are necessary to insure safety from lightning? (*b.*) Give the elements of a simple voltaic cell and (*c.*) the electric condition of those elements within and without the liquid.

6. (*a.*) A body weighs at the surface of the earth 1014 lb.; what would it weigh 1200 miles above the surface? (*b.*) Give the velocity of water issuing from an orifice, under a head of 81 feet. (*c.*) If 5 quarts of water weigh as much as 7 of alcohol, what is the specific gravity of the alcohol?

7. Find the kinetic energy of a 25 lb. ball that has fallen 3600 feet in vacuo. *Ans.* 90,000 foot-pounds.

8. Give the fundamental principle of Mechanics and illustrate its application by one of the mechanical powers.

9. (*a.*) Over how high a ridge can you continuously carry water in a siphon, where the minimum range of the barometer is 27 inches? (*b.*) Explain.

10. (*a.*) What is specific gravity? (*b.*) How do you find that of solids? (*c.*) What principle is involved in your method?

11. (*a.*) How much water per hour will be delivered from an orifice of 2 inches area, 25 feet below the surface of a tank kept full of water, not allowing for resistance? (*b.*) Give the law of magnetic attraction and repulsion. *Ans.* 14,998.44 gal.

12. (*a.*) State what you have been taught concerning the dipping needle. (*b.*) Define and illustrate magnetic induction.

13. (*a.*) Give the law of electric attraction and repulsion and illustrate by the pith-ball electroscope. (*b.*) Define conductors and non-conductors, electrics and non-electrics. (*c.*) Illustrate by an example of each.

14. (*a.*) Explain (by figures) electric induction. (*b.*) Explain the charging of a Leyden jar. (*c.*) When charged, what is the electric condition of the outside and inside of the jar?

15. (*a.*) Give the sources of atmospheric electricity and (*b.*) the effects of lightning.

16. (*a.*) What is the effect of breaking a magnet? (*b.*) Give a theory of magnetism that is competent to account for the properties of magnets, broken or unbroken.

17. (*a.*) How do soft iron and tempered steel differ as to susceptibility to magnetism? (*b.*) Describe one method of magnetizing a steel bar.

18. The influence of the earth's magnetism upon a magnetic needle is merely directive. (*a.*) Explain what this means. (*b.*) Show why it is so.

19. (*a.*) What is meant by electromotive force? (*b.*) Describe Grove's battery and its mode of action. (*c.*) Why are battery zincs generally amalgamated?

20. (*a.*) Describe Oersted's apparatus and (*b.*) tell what its use teaches. (*c.*) Describe the construction of the astatic galvanometer.

21. (*a.*) Describe an electro-magnet and (*b.*) tell what its advantages are. (*c.*) State the principle of the electric telegraph.

22. (*a.*) Describe a Ruhmkorff's coil and (*b.*) explain its action.

23. (*a.*) Define electrolysis and electrolyte. (*b.*) Describe the electrolysis of water. (*c.*) Give a clear account of some branch of electro-metallurgy. (*d.*) What is meant by the terms *electro-positive* and *electro-negative?*

24. (*a.*) Define physics. (*b.*) Name and define the three conditions of matter. (*c.*) What do you understand by energy? (*d.*) Explain what is meant by foot-pound.

25. (*a.*) What condition of the atmosphere is desirable for experiments in frictional electricity? (*b.*) Why? (*c.*) How could you show, experimentally, that there are two opposite kinds of electricity?

26. (*a.*) Describe the experiment with Faraday's bag and (*b.*) state what it teaches. (*c.*) Describe the dielectric machine and (*d.*) explain its action.

27. In an air-pump, the capacity of the cylinder is one-fourth that of the receiver. Under ordinary atmospheric conditions, they together contain 62 grains of air. Find the capacity (*a.*) of the receiver, (*b.*) of the cylinder. After 5 strokes of the piston, (*c.*) how many grains of air would be left in the receiver? What would be its tension (*d.*) in pounds per square inch? (*e.*) In *Kg.* per *sq. cm.?* (*f.*) In inches of mercury? *Ans.* (*e.*) 327.68 *g.*

28. (*a.*) Supposing we had two Leyden jars, one charged on the inside with positive electricity and the other with negative on the

inside; the two jars being insulated, can the jars be fully discharged by connecting the inner coats? (*b.*) Give reasons for your answer.

29. In a vessel having the dimensions of a cubic foot, sulphuric acid (sp. gr. = 1.83) stands eight inches high; give the pressure on the bottom and each side.

30. The lever of a hydrostatic press is six feet long, the fulcrum being at the end and one foot from the piston rod. The diameter of the tube is one inch; that of the cylinder, ten inches. The power is 25 lb.; give the effect. (See Appendix A.)

31. Find the joint resistance of three conductors of 10, 12 and 18 ohms arranged in multiple arc. *Ans.* 4.18 ohms.

32. (*a.*) Define equilibrium and its kinds. (*b.*) Give examples. (*c.*) How does the centre of gravity of any system, acted upon by an exterior force, move? (*d.*) Give an example.

33. (*a.*) Figure a simple barometer. (*b.*) Explain why the mercury stands above its level. (*c.*) What atmospheric pressure will sustain a column of mercury 24 inches high?

34. (*a.*) How is it proved that air has weight? (*b.*) What is the weight of air in a room 30 feet long, 20 feet wide and 10 feet high.

35. When a 1000 gram flask, containing 700 *g.* of water, was filled with the fragments of a mineral, it weighed 1450 *g.* Give the specific gravity of the mineral. *Ans.* 2.5.

36. A tank measuring 1 meter each way is filled with water: what will be the pressure on the bottom and sides?

37. (*a.*) What is meant by kinetic energy? (*b.*) By potential energy?

38. Two inelastic bodies are moving in opposite directions, one weighing 31 grams and having a velocity of 24 meters per second, the other weighing 22 grams and having a velocity of 18 meters per second: what is the united energy (*a.*) before and (*b.*) after impact? *Ans.* (*a.*) 1.27; (*b.*) 0.137 kilogrammeters.

39. Regarding the same bodies as moving in the same direction, what would be the energy (*a.*) before and (*b.*) after impact?

40. (*a.*) Draw a simple figure showing the essential parts of an air-pump and (*b.*) explain the process of forming a vacuum. (*c.*) If the capacity of the barrel be $\frac{1}{4}$ that of the receiver, how much air will remain in the receiver at the end of the fourth stroke of the piston? and (*d.*) what would be its elastic force compared with that of the external air? *Ans.* (*d.*) $\frac{256}{625}$.

41. The current of a Grove's battery with a certain resistance in the circuit is known to be $\frac{1}{6}$ ampere. Passing this current through a sine galvanometer, the coils had to be turned 9° to bring them parallel with the needle. (See Appendix L [2]). Some of the resistance

being removed, it is found that the coils have to be turned 70° to bring them parallel. What is the current in the latter case?

Ans. 1 ampere.

42. If a positively electrified ball be hung at the centre of a room, its charge will attract an equal amount of – electricity to the walls of the room. To what common piece of physical apparatus is this arrangement analogous?

43. What length of No. 6 pure copper wire (B. & S.) will have a resistance of 1 ohm? (See Appendix I.) *Ans.* 2433.09 ft.

44. If a foot of pure copper wire weighing 1 grain has a resistance of 0.2106 ohm and 20 feet of commercial copper wire weighing 150 grains has a resistance of 0.613 ohms, what is the percentage conductivity of the latter as compared with pure copper?

Ans. 91.6 per cent.

45. Sketch an arrangement by which a single line of wire can be used by an operator at either end to signal to the other; the condition of working being that whenever either operator is not sending a message, his instrument shall be *in circuit* with the line wire and *out of* circuit with the battery at his end.

46. Calculate, by Joule's law, the number of heat units developed in a wire whose resistance is 4 ohms when a steady current of 0.14 ampere is passed through it for ten minutes. *Ans.* 11.2 units of heat.

47. A dynamo has an E. M. F. of 839 volts and an internal (or interpolar) resistance of 10.9 ohms. Find the current strength when the external resistance is 73 ohms. *Ans.* 10 amperes.

48. I have 48 cells, each of 1.2 volts E. M. F. and each of 2 ohms internal resistance. What is the best way of grouping them together when it is desired to send the strongest possible current through a circuit whose resistance is 12 ohms? *Ans.* Group them three abreast.

49. The current from a certain dynamo (E. M. F. = 839.02 volts) was sent through a series of 16 arc lamps each having a resistance of 4.51 ohms. The line wire had a resistance of 0.8 ohm. The current measured 10.04 amperes. What was the resistance of the dynamo? *Ans.* 11.32 ohms.

50. Immediately after the discharge of a Leyden jar, the potential of its knob is zero. It, however, begins to rise and soon has a value that is a considerable part of the potential before discharge and with the same sign. Explain this.

51. What three varieties of energy appear when a Leyden jar is discharged?

52. How many heat units (calories) will be developed by a 10 ampere current flowing through a coil of 50 ohms resistance in a quarter of an hour? *Ans.* 1,080 calories.

53. A current of 9 amperes worked an electric arc light and on measuring the difference of potential between the two carbons by an electrometer it was found to be 140 volts. What was the amount of power absorbed in the arc? *Ans.* 1.69 H. P.

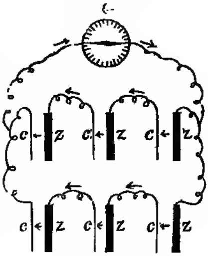


FIG. 252.

54. If the cells represented in Fig. 252 have each an internal resistance of 4 ohms, what is the resistance of the external circuit, *G*, if the battery is working at its greatest possible efficiency? *Ans.* 6 ohms.

55. The same strength of current that will heat an inch of platinum wire to whiteness will similarly heat a yard of the same wire. Explain why it is necessary to use more cells thus to heat a yard than it does to heat an inch of the wire.

56. Five Daniel cells, each with an E. M. F. of 1.1 volts and an internal resistance of 2.2 ohms are joined in series. The external circuit consists of 16743 feet of No. 14 copper wire (B. & S.) (See Appendix I.) (*a.*) What is the resistance of the external circuit? (*b.*) What is the current strength? *Ans.* (*b.*) 0.1 ampere.

57. Show that with an unlimited number of cells like that just described, joined in series, the current cannot exceed 0.5 amperes.

58. What is the total energy of the current of the dynamo, operated as described in Exercise 1, page 349? *Ans.* { 8417.94 watts. 11.28 horse-power.

59. Explain the use and construction of a relay.

60. Suppose 1000 incandescence lamps to be placed parallel in the circuit of a dynamo. Each lamp has a hot resistance of 50 ohms and requires a current of 1 ampere. (*a.*) What will be the current strength developed by the dynamo? (*b.*) What is the resistance of the lamp circuit, ignoring the resistance of the leading wires? (*c.*) What is the necessary difference of potential between the binding posts of the dynamo? (*d.*) If the resistance of the dynamo itself is 0.005 ohm, what is the total E. M. F.? (*e.*) How many watts will be expended in each lamp? (*f.*) If 500 of the lamps be turned off (open circuited), what will the resistance of the lamp circuit become? (*g.*) If the E. M. F. of the dynamo be kept constant by change of speed or otherwise, what will be the current developed by the dynamo with the 500 lamps? (*h.*) What will be the current then supplied to each lamp?

Ans. (*a.*) 1000 amperes; (*b.*) 0.05 ohm; (*c.*) 50 volts; (*d.*) 55 volts; (*e.*) 50; (*f.*) 0.1 ohm; (*g.*) 523.81 amperes; (*h.*) 1.047 amperes.

HONORARY PROBLEMS.

1. Two incandescence lamps with resistances of 16.9 and 32 ohms respectively were joined in series with a series of 40 similar voltaic cells having a total resistance of 20 ohms. The current measured 1.16 amperes. What will be the strength of current that a series of 60 such cells will send through a series of four lamps having resistances of 16.9, 32, 20 and 16 ohms respectively? *Ans.* 1.043 amperes.

2. What would have been the strength of current in this case if the area of the battery plates had been doubled, all things else remaining the same? *Ans.* 1.2 amperes.

3. It required 15.3 H. P. to drive a certain dynamo that had a resistance of 10.5 ohms and developed a current of 10 amperes through an external resistance of 73 ohms. (The "duty" of a dynamo is the ratio of the total electrical energy developed to the work performed in turning the armature in the magnetic field). What is the *duty* of the dynamo in question? *Ans.* 73 per cent.

4. The "commercial efficiency" of a dynamo is the ratio of the electrical energy appearing in the external circuit to the work performed in turning the armature in the magnetic field. What is the *commercial efficiency* of the dynamo above mentioned? *Ans.* 64 per cent.

CHAPTER VII.

SOUND.

SECTION I.

NATURE, REFRACTION AND REFLECTION OF SOUND.

477. Definition of Sound.—*Sound is the mode of motion that is capable of affecting the auditory nerve.*

(*a.*) The word sound is used in two different senses. It is often used to designate a *sensation* caused by waves of air beating upon the organ of hearing; it is also used to designate these aërial waves themselves. The former meaning refers to a physiological or psychological process; the latter to a physical phenomenon. If every living creature were deaf there could be no sound in the former sense, while in the latter sense the sound would exist but would be unheard. The definition above considers sound in the physical sense only.

478. Undulations.—In beginning the study of acoustics, it is very important to acquire a clear idea of the nature of undulatory motion. When a person sees waves approaching the shore of a lake or ocean, there arises the idea of an onward movement of great masses of water. But if the observer give his attention to a piece of wood floating upon the water, he will notice that it merely rises and falls without approaching the shore. He may thus be enabled to correct his erroneous idea of the onward motion of the water. Again, he may stand beside a field of ripening grain and, as the breezes blow, he will see a series of waves pass before him. But if he reflect and observe carefully, he will see clearly that there is no movement of matter from one side of the field to the other; the grain-ladened stalks merely bow and raise their heads. Most persons are familiar with similar wave movements in ropes, chains and carpets. *Each material particle has a motion, but that motion is vibratory, not progressive. The only thing that has an onward movement is the pulse or wave, which is only a form or change in the relative positions of the particles of the undulating substance.*

(*a.*) The motion of the wave must be clearly distinguished from the motion of particles which constitute the wave. The wave may travel to a great distance; the journey of the individual particle is very limited.

479. Wave Period.—When a medium is traversed by a series of similar waves, each particle is in a state of continued vibration. These vibrations are alike, they being as truly isochronous (§ 143) as those of the pendulum. *The time required for a complete vibration is called the period, and is the same for all the particles.*

480. Wave Length.—In such a series of similar waves, measuring in the direction in which the waves are travelling, *the distance from any vibrating particle to the next particle that is in the same relative position or "phase" is called a wave length.* In the case of water waves, the distance from one crest to the next is a wave length. (See *First Principles,* § 321, *a.*)

481. Amplitude.—*Amplitude means the distance between the extreme positions of the vibrating particle,* or the length of its journey. As in the case of the pendulum, amplitude and period are independent of each other. Amplitude is also independent of wave length.

482. Relation of Period, Wave Length and Velocity.—During one period there will be one complete vibration, and the wave will advance one wave length. The velocity of the wave may be found by multiplying the wave length by the number of vibrations per second. Conversely, *the wave length may be found by dividing the velocity by the number of vibrations.*

483. Cause of Sound.—*All sound may be traced to the vibrations of some material body.* When a bell is struck, the edges of the bell are set in rapid vibration, as may be seen by holding a card or finger nail lightly upon the edge. The particles of the bell strike the adjacent particles of air, these pass the motion thus received on to the air particles next beyond, and these to those beyond.

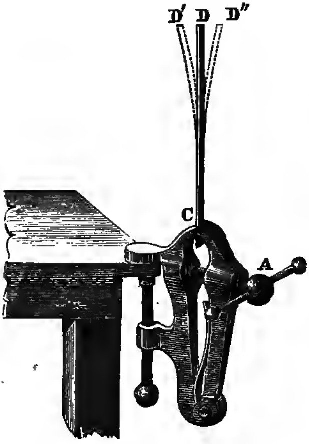


Fig. 253.

(*a.*) That sound is due to vibratory motion may be shown by numerous experiments. Holding one end of a straight spring, as a hickory stick, in a vise, pull the free end to one side and let it go. Elasticity will return it to its position of rest, kinetic energy will carry it beyond, and so on, a vibratory motion being thus produced. When the spring is long, the vibrations may be seen. By lowering the spring in the vise, the vibrating part is shortened, the vibrations reduced in amplitude and increased in rapidity. As the spring is shortened, the vibrations become invisible but audible, showing that a sufficiently rapid vibratory motion may produce a sound.

(*b.*) Suspend a pith ball by a thread so that it shall hang lightly against one prong of a tuning-fork. When the fork is sounded, the pith ball will be thrown off by the vibrations of the prongs. Other illustrations of the same truth will be observed as we go on.

(*c.*) The vibrations of a tuning-fork may be represented in the following manner: A glass plate which has been blackened by holding it in a petroleum flame is arranged so as to slide easily in the grooved frame *F*. A pointed piece of metal is attached to one of the prongs of the fork. When the fork is made to vibrate, the point placed against the smoked plate and the plate drawn along rapidly in the grooves, the point traces on the glass an undulating line which represents fairly the vibratory movement of the prong.

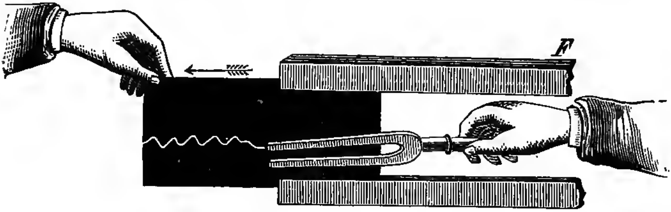


FIG. 254.

484. Propagation of Sound.—Sound is ordinarily propagated through the air. Tracing the sound from its source to the ear of the hearer, we may say that the first layer of air is struck by the vibrating body. The particles of this layer give their motion to the particles of the next layer, and so on until the particles of the last layer strike upon the drum of the ear.

(*a.*) This idea is beautifully illustrated by Prof. Tyndall. He imagines five boys placed in a row as shown in Fig. 255. "I suddenly push *A*; *A* pushes *B* and regains his upright position; *B* pushes *C*; *C* pushes *D*; *D* pushes *E*; each boy after the transmission of the push, becoming himself erect. *E*, having nobody in front, is thrown forward. Had he been standing on the edge of a precipice he would have fallen over; had he stood in contact with a window, he would have broken the glass; had he been close to a drum-head, he would have shaken the drum. We could thus transmit a push through a row of a hundred boys, each particular boy, however, only swaying to and fro. Thus also we send sound through the air, and shake the drum of a distant ear, while each particular particle of the air concerned in the transmission of the pulse makes only a small oscillation." (See *First Prin.*, Exps. 141–144.)

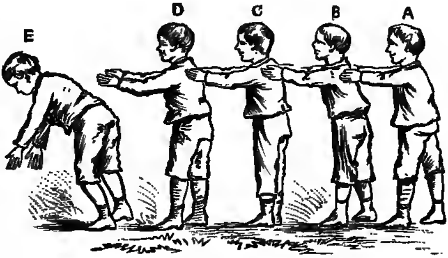


FIG 255.

485. Sound Waves.—The layers of air are crowded more closely together by each outward vibration of the sounding body; a condensation of the air is thus produced As the sonorous body vibrates in the opposite direction,

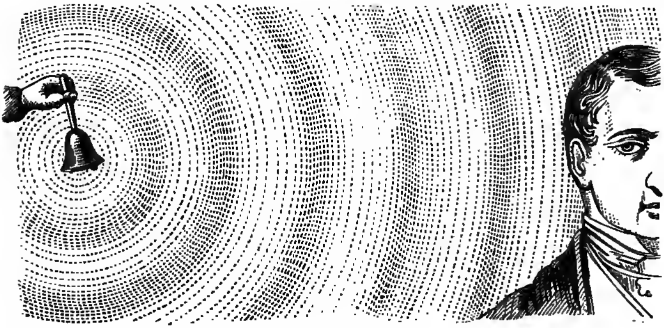


FIG. 256.

the nearest layer of air particles follows it; a rarefaction of the air is thus produced. *A sound wave, therefore, consists of two parts, a condensation and a rarefaction.* The motion of any air particle is backward and forward in the line of propagation, and not "up and down" across that line, as in the case of water waves. A series of complete sound waves consists of alternate condensations and rarefactions in the form of continually increasing spherical shells, at the common centre of which is the sounding body. Any line of propagation of the sound would be a radius of the sphere.

486. Sound Media.—The air particles impart their motion to other particles because of their elasticity. *Any elastic substance may become the medium for the transmission of sound, but such a medium is necessary.* The elasticity of a body may be measured by the resistance it opposes to compression. The less the compressibility, the greater the elasticity.

(*a.*) That sound is not transmitted in a vacuum is shown as follows: A large glass globe, provided with a stop-cock, contains a small bell suspended by a thread. When the air is pumped from the globe and the globe shaken, no sound is heard, although the clapper of the bell is seen to strike

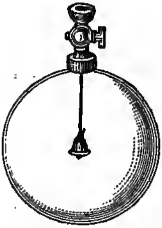


FIG. 257.

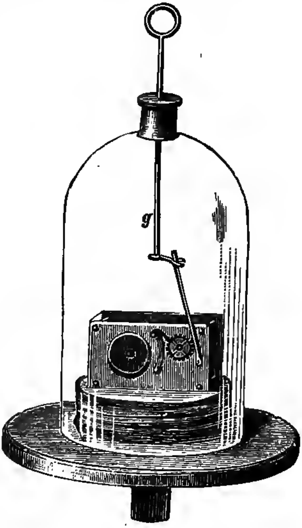


FIG. 258.

against the bell. Readmitting the air, and again shaking the globe, the sound is plainly heard. (See Fig. 257.)

(*b.*) A small music box, or a clock-work arrangement for striking a bell (Fig. 258), may be supported upon a thick cushion of felt or cotton-batting, and placed under the capped receiver of an air-pump. When the receiver is exhausted, and the machinery started by the rod *g*, the motion may be seen but hardly any sound will be heard. If the support were perfectly inelastic and the exhaustion complete, no sound would be audible. The experiment may be made more perfect by filling the exhausted receiver with hydrogen and again exhausting the gas. (See *First Principles*, Exps. 146–148.)

487. Velocity of Sound in Air.—It is a familiar fact that the transmission of sound is not instantaneous. The blow of a hammer is often seen several seconds before the consequent sound is heard; steam escaping from the whistle of a distant locomotive becomes visible before the shrill scream is audible; the lightning precedes the thunder. As we shall see further on, the time required for the propagation of light through terrestrial distances is inappreciable. Hence the interval between the two sensations of seeing and hearing is required for the transmission of the sound. This interval being observed and the distance being known, the velocity is easily computed. By such means it has been found that *the velocity of sound in air at the freezing temperature is about 332 m., or 1090 ft. per second.* There is some reason for believing that very loud sounds travel somewhat more rapidly than sounds of ordinary loudness. With this exception it may be said that, in a given medium, all sounds travel with the same velocity.

488. Velocity in Other Media.—*The velocity of sound depends upon two considerations—the elasticity and the density of the medium. It varies directly as the square root of the elasticity, and* *inversely as the square root of the density.* At the freezing temperature, sound travels through oxygen with a velocity of 1040 feet, and through hydrogen with a velocity of 4164 feet per second.

$$v = \sqrt{\frac{E}{D}}$$

(*a.*) It is a very common mistake to think that an increase of density causes an increase of velocity. It is known, *e.g.*, that sound travels more rapidly in water than in air; that water is more dense than air; hence, say the superficial, sound travels most rapidly in the densest bodies. *It does not follow.* Other things being equal, the denser the medium, the less the velocity of the motion. A little reflection will show that this must be so; experiments will verify the conclusion. *In wave motion, the particles of the medium constitute the thing that is moved.* With a given expenditure of energy, a number of light particles is moved more rapidly than an equal number of heavy particles (§ 157).

489. Effect of Temperature Upon Velocity.—An increase of the temperature of the air increases its elasticity and decreases its density. We might, therefore, expect sound to travel more rapidly in warm than in cold air. Experiment confirms the conclusion. *There is an added velocity of about 1.12 feet for every Fahrenheit degree, or of about 2 feet for every centigrade degree of increase of temperature.* (The freezing temperature is 32° F, or 0° C.)

490. Momentary and Continuous Sounds.—A sound may be momentary or continuous. A momentary sound consists of a single pulse produced by a single and sudden blow. A continuous sound consists of a rapid succession of pulses. The ear is so constructed that its vibrations disappear very rapidly but the disappearance is not instantaneous. *If the motion imparted* *to the auditory nerve by each individual pulse continue until the arrival of its successor, the sound will be continuous.*

(*a.*) Momentary sounds may be produced by pounding with a hammer, stamping with the foot, clapping the hands or drawing a stick slowly along the pickets of a fence. Continuous sounds may be produced by sawing boards or filing saws. They constitute the rattling of wheels over a stony pavement, the roar of waves or the crackling of a large fire.

491. Noise and Music.—The sensation produced by a series of blows coming at irregular intervals, is unpleasant and the sound is called a noise. But when the air waves come with sufficient rapidity to render the sound continuous and with perfect regularity, the sensation is pleasant and the sound is said to be musical. *To secure this pleasing smoothness of music, the sounding body must vibrate with the unerring regularity of the pendulum, but impart much sharper and quicker shocks to the air. Every musical sound has a well-defined period and wave length.*

492. Elements of Musical Sounds.—Musical sounds or tones have three elements—intensity or loudness, pitch, and *timbre* or quality. The first two of these we shall consider at once, the third, a little further on.

493. Intensity and Amplitude.—*Intensity or loudness of sound depends upon the amplitude of vibration.* The greater the amplitude, the louder the sound.

(*a.*) If the middle of a tightly-stretched cord or wire, as a guitar string, be drawn aside from its position of rest and then set free, it will vibrate to and fro across its place of rest, striking the air and sending sound waves to the ear. If the middle of the string be drawn aside to a greater distance and then set free, the swing to and fro will be increased, harder blows will be struck upon the air, and the air particles will move forward and backward through a greater distance. In other words, the amplitude of vibration has been increased. But this change in the aërial wave produces a change in the sensation. We still recognize the pitch to be the same as before; the tone is neither higher nor lower. We even recognize it still as being produced by a guitar string. The only difference is that the sensation is more intense; we say that the sound is louder.

494. Intensity and Distance.—*The intensity of sound varies inversely as the square of the distance from the sounding body.* Hence, the distance to which a sound may be heard depends upon its intensity.

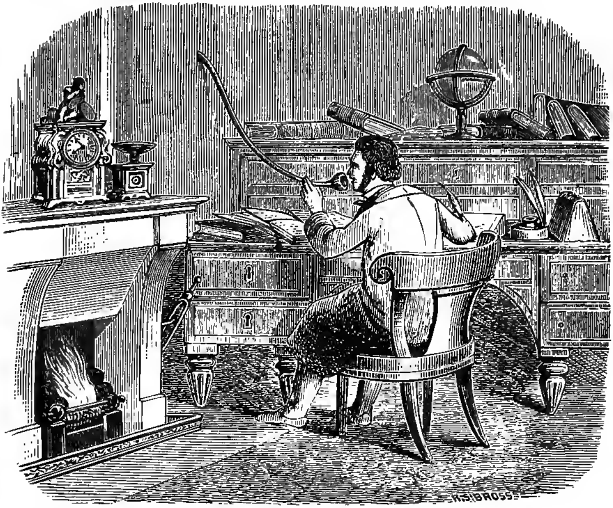


FIG. 259.

495. Acoustic Tubes.—If the sound wave be not allowed to expand as a spherical shell, the energy of the wave cannot be diffused. This means that its intensity will be maintained. In acoustic tubes (Fig. 217) this diffusion is prevented; *the waves are propagated in* *only one direction.* In this way, sound may be transmitted to great distances without considerable loss of intensity. (See *First Principles,* Exp. 149.)

496. Pitch.—The second element of a musical sound is pitch, by which we mean the quality that constitutes the difference between a low or grave tone and a high tone. All persons are more or less able to recognize differences in pitch. A person who is able to judge accurately of the pitch of sounds is said to have a "good ear for music." *The pitch of a sound depends upon the rapidity of vibration of the sounding body,* or, in other words, upon the rate at which sound pulses follow each other. The more rapid the vibrations, the higher the tone.

497. Experimental Proof of the Cause of Pitch. — That pitch depends upon rapidity of vibration, may be roughly shown by drawing the finger nail across the teeth of a comb, slowly the first time and rapidly the second time. It may be shown more satisfactorily by means of Savart's wheel, shown in Fig. 260. This consists of a heavy metal ratchet-wheel, supported on an iron frame and pedestal. The wheel may be set in rapid revolution by a cord wound around the axis. By holding a card against the teeth, when in rapid motion, a shrill tone will be produced, gradually falling in pitch as the speed is lessened.

FIG. 260.

(*a.*) If the sounding body and the listening ear approach each other, the sound waves will beat upon the ear with greater rapidity. This is equivalent to increasing the rapidity of vibration of the sounding body. The opposite holds true when the sounding body and the ear recede from each other. This explains why the pitch of the whistle of a railway locomotive is perceptibly higher when the train is rapidly approaching the observer, than when it is rapidly moving away from him.

498. Relation between Pitch and Period.—*Rate of vibration and period are reciprocals.* If the rate of vibration be 256 per second, the period is $\frac{1}{256}$ of a second. The period may, therefore, be used to measure the pitch; the greater the period, the lower the pitch.

499. Relation between Pitch and Wave Length.—Since, in a given medium, all sounds travel with the same velocity, the rate of vibration determines the wave length. If the sounding body vibrate 224 times per second, 224 waves will be started each second. If the velocity of the sound be 1120 feet, the total length of these 224 waves must be 1120 feet, or the length of each wave must be five feet. If another body vibrate twice as fast, it will crowd twice as many waves into the 1120 feet; each wave will be only two and a half feet long. Thus wave length may be used to measure the pitch—the greater the wave length, the lower the pitch.

500. Refraction of Sound.—We have a clear idea of sound waves advancing as concentric, spherical shells, but we are far more familiar with the idea of sound advancing in definite straight lines. This idea is also correct, the lines being radii of the sphere. We may thus speak of lines or "rays" of sound, meaning thereby the direction in which the sonorous pulses are propagated. The ray is necessarily perpendicular to the wave. When the noise of the street is heard by a person in a closed room, the sound must have passed from the air without to the solid matter of the walls, and from this to the air within. When sound thus passes obliquely from one medium to another, the rays are bent. *This bending of a sound ray is called refraction of sound.*

501. A Sound Focus.—Ordinarily, sound rays are divergent. The sound is therefore continually diminishing in intensity. By means of their refrangibility, they may be made convergent. If the divergent rays strike the side of a sack shaped like a double convex lens, made of two films of collodion, or very thin India rubber, and filled with carbonic acid gas (CO_2), their divergence will be diminished; they may thus be made parallel, or even convergent, after passing through the sack. At the point where these rays converge their total energy will be concentrated, and the intensity of the sound be thus increased. The point where the refracted rays intersect is called the focus of the lens. The laws of refracted sound are the same as those of refracted light, to be studied further on.

(*a.*) If a watch be hung near such a refractor, its ticking may be heard by placing the ear at the focus on the other side of the sack; when the sack is removed, the ticking is no longer audible. A few trials will enable the experimenter to determine the proper positions for the watch, the lens and the ear. The refraction directs to the ear all the energy exerted upon the anterior surface of the sack. This energy is sufficient to excite the sensation of hearing. A little reflection will show that when the sack is removed, the energy exerted upon the smaller surface of the tympanum at the

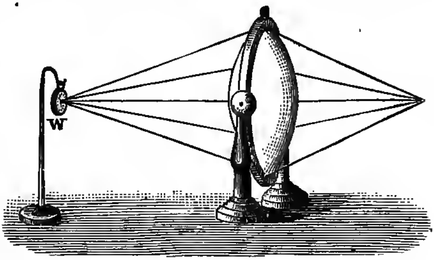


FIG. 261.

greater distance is very much diminished. This lesser energy is unable to excite the auditory nerve to action, and the ticking of the watch is unheard.

502. Reflection of Sound.—When a sound ray strikes an obstacle, it is reflected in obedience to the principle given in § 97. This fact is turned to account in the case of "conjugate reflectors" of sound. Fig. 262 represents the section of two parabolic reflectors *mn* and *op*. It is a peculiarity of such reflectors that rays starting from the focus, as *F*, will be reflected as parallel rays, and that parallel rays falling upon such a reflector will converge at the focus, as *F′*. Hence, two such reflectors may be placed in such a position that sound waves starting from one focus shall, after two reflections, be converged at the other focus. *Two reflectors so placed are said to be conjugate to each other.* This principle underlies the phenomena of whispering galleries.

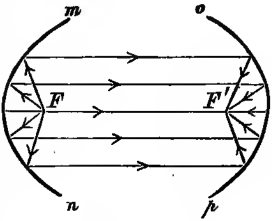


FIG. 262.

(*a.*) "The great dome of St. Paul's Cathedral in London is so constructed that two persons at opposite points of the internal gallery, placed in the drum of the dome, can talk together in a mere whisper. The sound is transmitted from one to the other by successive reflections along the course of the dome." A similar phenomenon is observable in the dome of the Capitol at Washington.

503. Experiment.—At the focus of a curved reflector, place a watch or other suitable sounding body. Directly facing it, but at a distance so great that the ticking is unheard, place a similar reflector. When the ear is placed at the focus of the second mirror, as shown in Fig. 263, the ticking is plainly heard.

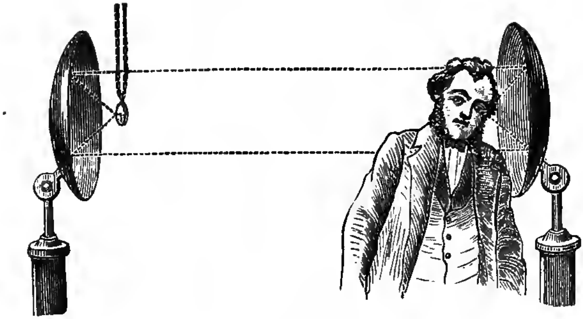


FIG. 263.

(*a.*) In the experiment above described, it is plain that many of the rays reflected by the first mirror are intercepted before they reach the second mirror. This may be remedied, in part, by the use of an ear-trumpet, the larger end being held at the focus of the second reflector. The ear-trumpet may be a glass funnel, with a piece of rubber tubing leading from its smaller end to the ear. The experiment may be modified by using a single reflector, the watch being placed a little further from the reflector. The proper positions for the watch and the funnel are easily determined by experiment. They are *conjugate foci.*

504. Echo.—*When a sound, after reflection, is audible, it is called an echo.* The distinctness with which it is heard depends upon the distance of the ear from the reflecting surface. A very quick, sharp sound may produce an echo even when the reflecting surface is not more than fifty or sixty feet away, but for articulate sounds a greater distance is necessary.

(*a.*) Few, if any, persons can pronounce distinctly more than about five syllables in a second. At the ordinary temperature, sound travels about 1120 feet per second. In a fifth of that time it would travel about 224 feet. If, therefore, the reflecting surface be 112 feet distant, the articulate sound will go and return before the next syllable is pronounced. The two sounds will not interfere, and the echo will be distinctly heard. If the reflecting surface be less than this distance, the reflected sound will return before the articulation is complete and confusedly blend with it. If the reflector be 224 feet distant, there will be time to pronounce two syllables before the reflected wave returns. The echo of both syllables may then be heard; and so on. The echo may be heard sometimes when the direct sound cannot be heard.

(*b.*) Suppose the speaker to stand 1120 feet from the reflecting substance. If then he speak ten syllables in two seconds, the echo of the first will return just as the last is spoken; the echo of each syllable will be distinct. But if he continues to speak, the direct and the reflected sounds will become blended and confused. The reflecting surface should be a large, vertical wall, or similar object, as a huge rock.

(*c.*) When two opposite surfaces, as parallel walls, successively reflect the sound, *multiple echoes* are heard. Sometimes an echo is thus repeated 20 or 30 times.

EXERCISES.

1. If 18 seconds intervene between the flash and report of a gun, what is its distance, the temperature being 82° F.?

2. What will be the length of the sound waves propagated through air at a temperature of 15° C. by a tuning-fork that vibrates 224 times per second?

3. State clearly the difference between a transverse and a longitudinal wave.

4. Determine the temperature of the air when the velocity of sound is 1150 feet per second.

5. If *A* is 50 *m.* from a bell, and *B* is 70 *m.* from it, how will the loudness of the sound as heard by *B* compare with the loudness as heard by *A*?

6. A shot is fired before a cliff, and the echo heard in six seconds. The temperature being 15° C. find the distance of the cliff.

7. A certain musical instrument makes 1100 vibrations per second. Under what conditions will the sound waves be each a foot long?

8. How many vibrations per second are necessary for the formation of sound waves four feet long, the velocity of sound being 1120 feet? What will be the temperature at the time of the experiment?

9. Taking the velocity of sound as 332 *m.*, find the length of a wave if there are 830 vibrations per second.

10. The waves produced by a man's voice in common conversation are from eight to twelve feet long. If the velocity of sound be

1128 feet, find the corresponding numbers of vibrations of vocal chords.

11. A person stands before a cliff and claps his hands. In $\frac{3}{8}$ of a second he hears the echo. How far distant was the cliff?

Recapitulation.—To be amplified by the pupil for review.

- SOUND.
  - **DEFINITION AND CAUSE.**
  - **WAVES.**
    - UNDULATIONS.
    - MODE OF PROPAGATION.
    - PERIOD AND LENGTH.
    - AMPLITUDE.
    - PARTS.
      - CONDENSATION.
      - RAREFACTION.
  - **MEDIA.**
  - **VELOCITY.**
    - IN AIR.
      - AT FREEZING TEMPERATURE.
      - AT OTHER TEMPERATURES.
    - IN OTHER MEDIA.
  - **MOMENTARY.**
  - **CONTINUOUS.**
    - NOISY.
    - MUSICAL.
      - LOUDNESS.
        - *Cause.*
        - *Acoustic Tubes.*
      - PITCH....... *Cause.*
      - RELATION BETWEEN PITCH AND PERIOD.
      - QUALITY OR TIMBRE.
  - **REFRACTION AND ACOUSTIC FOCI.**
  - **REFLECTION.**
    - LAW.
    - WHISPERING GALLERIES.
    - ECHOES.

SECTION II.

THE TELEPHONE AND PHONOGRAPH.—COMPOSITION AND ANALYSIS OF SOUNDS.

Note.—Before beginning the study of the telephone, the pupil should carefully review §§ 468, 469.

505. The Telephone.—This instrument is represented in section by Fig. 264. *A* is a permanent bar magnet, around one end of which is wound a coil, *B*, of fine copper wire carefully insulated. The ends of this coiled wire are attached to the larger wires, *CC*, which communicate with the binding posts, *DD*. In front of the magnet and coil is the soft iron diaphragm, *E*, which corresponds to the disc, *a*, of Fig. 249. The distance between *E* and the end of *A* is delicately adjusted by the screw, *S*. In front of the diaphragm, is a wooden mouth-piece with a hole about the size of a dime, at the middle of the diaphragm and opposite the end of the magnet. The outer case is made of wood or of hard rubber. The external appearance of the complete instrument is represented by Fig. 265.

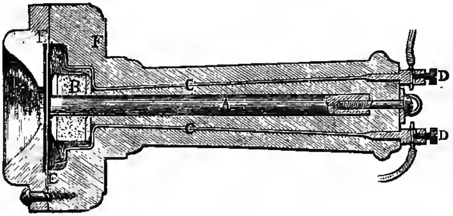


FIG. 264.

The binding posts of one instrument being connected by wires with the binding posts of another at a distance, conversation may be carried on between them.

FIG. 265.

506. Action of the Telephone.—When the mouth-piece is brought before the lips of a person who is talking, air waves beat upon the diaphragm and cause it to vibrate. The nature of these vibrations depends upon the loudness, pitch and *timbre* of the sounds uttered. Each vibration of the diaphragm induces an electric current in the wire of *B*. These currents are transmitted to the coil of the connected telephone, at a distance of, perhaps, several miles, and there produce, in the diaphragm of the instrument, vibrations exactly like the original vibrations produced by the voice of the speaker. These vibrations of the second diaphragm send out new air waves that are very faithful counterparts of the original air waves that fell upon the first diaphragm. The two sets of air waves being alike, the resulting sensations produced in the hearers are alike. Not only different words but also different voices may be recognized. The arrangement being the same at both stations, the apparatus works in either direction. No battery is necessary with this arrangement. (See Appendix O.)

(*a.*) The reproduced sound is somewhat feeble but remarkably clear and distinct. The second telephone should be held close to the ear of the listener. Sometimes there are, in the same circuit, two or more instruments at each station, so that each operator may hold one to the ear and the other to the mouth; or the listener may place one at each ear. When the stations are a considerable distance apart, one binding post of each instrument may be connected with the earth, as in the case of the telegraph (§ 444).

(*b.*) It is to be distinctly noticed that the *sound waves* are not transmitted from one station to the other. "The air waves are spent in producing mechanical vibrations of the metal; these create magnetic disturbances which excite electrical action in the wire, and this again gives rise to magnetic changes that are still further converted into the tremors of the distant diaphragm, and these finally reappear as new trains of air waves that affect the listener."

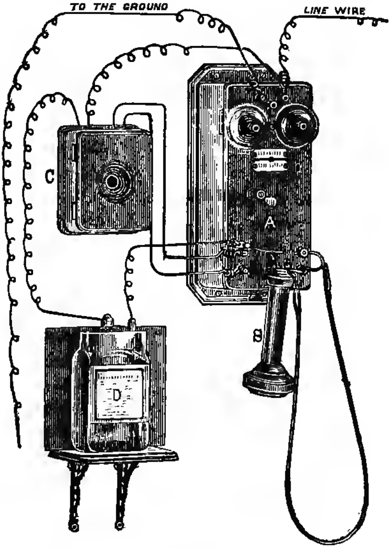


FIG. 266.

507. The Transmitter.—In practice, a transmitter, shown at *C* in Fig. 266, is generally used. The vibrations of the diaphragm of *C*, when acted upon by sound waves, produce a varying pressure upon a carbon button placed in the circuit of a galvanic battery, *D*. This varying pressure results in a varying resistance to the passage of the current through the button and, consequently, in variations in the current itself. This varying current, passing through the primary circuit of a small induction coil in the box, *C*, induces a current in the secondary circuit thereof. This current, thus induced, flows over the telephone wires and, at the other station, passes through a telephone like that shown at *B*, which is held close to the ear of the listener. The message is transmitted by *C* at one station and received by *B*, of a similar instrument, at the other station.

At each station is placed an electric bell, *A*, which may be rung from the other station, for the purpose of attracting attention. When the stations are a considerable distance apart, one binding post of each instrument may be connected with the earth, as in the case of the telegraph.

(*a.*) In most of our cities, the telephones are connected by wire with a central station, called a telephone exchange. The "Exchange" may thus be connected with the houses of hundreds of patrons in all parts of the city or even in different cities. Upon request by telephone, the attendant at the central station connects the line from any instrument with that running to any other instrument. Thus, each subscriber may communicate directly with any other subscriber to the exchange.

508. The Phonograph.—This is an instrument for recording sounds and reproducing them after any length of time. (See Appendix P.)

(*a.*) The receiving apparatus consists of a mouth-piece and vibrating disc like those of the telephone. At the back of the disc is a short needle or style for recording the vibrations upon a sheet of tin-foil moving under it. This tin-foil is placed upon a metal cylinder about a foot (30 *cm.*) long. The cylinder has a spiral groove upon its curved surface and a similar thread upon its axis, which turns in a fixed nut. As the cylinder is turned by a crank, the threads upon the axis give the cylinder a lengthwise motion. The style is placed in position over one of the tin-foil covered grooves of the cylinder. As the cylinder revolves, a projection in front of the style crowds the foil down into the groove. The needle follows in the channel thus made and, as it vibrates, records a succession of dots in the tin-foil. *These dots constitute the record.* To the naked eye they look alike, but the microscope reveals differences corresponding to pitch, loudness, and *timbre.*

(*b.*) To reproduce the sound, the style is lifted from the foil, the cylinder turned back to its starting point, the style placed in the beginning of the groove and the crank turned. The style passes through the channel and drops into the first indentation; the disc follows it. The style rises and drops into each of the succeeding indentations, the disc following its every motion with a vibration. The original vibrations made the dots; the dots are now making similar vibrations. Sound waves made the original vibrations; now the reproduced vibrations create similar sound waves. The reproduced sounds are a little muffled but remarkably distinct, each of the three qualities (§ 492) being recognizable. The principle may be applied to any implement or toy that makes a sound as well as to the voice. Perfectly simple; equally wonderful.

Experiment 1.—The effect of repeated impulses, each feeble *but acting at the right instant,* may be forcibly illustrated as follows: Support a heavy weight, as a bucket of coal, by a long string or wire. To the handle of a bucket, fasten a fine cotton thread. By repeated pulls upon the thread, each pull, after the first one, being given just as the pendulum is beginning to swing toward you from the effect of the previous pull, the weight may be made to swing through a large arc, while a single pull *out of time* will snap the thread. A little practice will enable you to perform the experiment neatly.

Experiment 2.—Vary the last experiment by setting the pendulum in motion by well-timed puffs of air from the mouth or from a hand bellows. The same principle is illustrated in the action of the spring board, familiar to most boys, who know that the desired effect can be secured only by "keeping time." Soldiers are often ordered to "break step" in crossing a bridge, lest the *accumulated energy* of many footfalls in unison break the bridge.

Experiment 3.—Suspend several pendulums from a frame as shown in Fig. 267. Make two of equal length so that they will vibrate at the same rate. *Be sure that they will thus vibrate.* The other pendulums are to be of different lengths. Set *a* in vibration. The swinging of *a* will produce slight vibrations in the frame which will, in turn, transmit them to the other pendulums. As the successive impulses thus imparted by *a* keep time with the vibrations of *b*, this energy accumulates in *b*, *which is soon set in perceptible vibration.* As these impulses do not keep time with the vibrations of the other pendulums, there can be no such *accumulation of energy* in them, for many of the impulses will act in opposition to the motions produced by previous impulses and tend to destroy them.

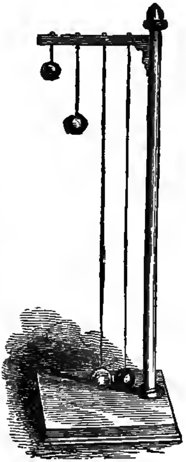


FIG. 267.

Experiment 4.—Tune to unison two strings upon the same sonometer (Fig. 268). Upon one string, place two or three paper riders. With a violin bow, set the other string in vibration. The sympathetic vibrations thus produced will be shown by the dismounting of the riders, whether the vibrations be audible or not. Change the tension of one of the strings, thus destroying the unison. Repeat the experiment and notice that *the sympathetic vibrations are not produced.* See App. Q.

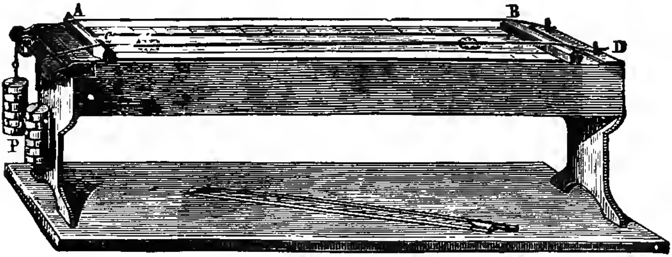


FIG. 268.

Experiment 5.—Place, several feet apart, two tuning-forks mounted upon resonant cases. The forks should have the same tone and the cases should rest upon pieces of rubber tubing to prevent the transferrence of vibratory motion to and through the table.

FIG. 269.

Sound the first fork by rapidly separating the two prongs with a rod or by rubbing it with a violin bow. Notice the pitch. At the end of a second or two, touch the prongs to stop their motion and sound. It will be found that the second fork has been set in motion by the repeated blows of the air and is giving forth a sound of the same pitch as that originally produced by the first fork. Fasten, by means of wax, a 3-cent silver piece or other small weight to one of the prongs of the second fork. *An attempt to repeat the experiment will fail.* When the two forks are in unison, their periods are the same. The second and subsequent pulses sent out by the first fork strike the second fork, already vibrating from the effect of the first pulse, in the same phase of vibration and thus each adds its effect to that of all its predecessors. If the forks be not in unison, their periods will be different and but few of the successive pulses can strike the second fork in the same phase of vibration; the greater number will strike it at the wrong instant.

509. Sympathetic Vibrations.—The string of a violin may be made to vibrate audibly by sounding near it a tuning-fork of the same tone. By prolonging a vocal tone near a piano, one of the wires seems to take up the note and give it back of its own accord. If the tone be changed, another wire will give it back. In each case, that wire is excited to audible action, which is able to vibrate at the same rate as do the sonorous waves that set it in motion. Thus the vibrations of the strings may produce sonorous waves and the waves, in turn, may produce vibrations in another string. The most important feature of the phenomenon is that *the string absorbs only the particular kind of vibration that it is capable of producing.*

Experiment 6.—Strike a tuning-fork held in the hand. Notice the feeble sound. Strike the fork again and place the end of the handle upon a table. The loudness of the sound heard is remarkably increased.

Experiment 7.—Strike the fork and hold it near the ear, counting the number of seconds that you can hear it. Strike the fork again with equal force; place the end of the handle on the table and count the number of seconds that you can hear it.

510. Sounding-Boards. — In the case of the sonometer, piano, violin, guitar, etc., the sound is due more to the vibrations of the resonant bodies that carry the strings than to the vibrations of the strings themselves. The strings are too thin to impart enough motion to the air to be sensible at any considerable distance; but as they vibrate, their tremors are carried by the bridges to the material of the sounding apparatus with which they are connected. These larger surfaces throw larger masses of air into vibration and thus greatly intensify the sound. It necessarily follows that the energy of the vibrating body is sooner exhausted; the sounds are of shorter duration.

(*a.*) This sounding apparatus usually consists of thin pieces of wood that are capable of vibrating in any period within certain limits. The vibrations of these large surfaces and of the enclosed air produce the sonorous vibrations. The excellence of a Cremona violin does not lie in the strings, which may have to be replaced daily. The strings are valuable *to determine the rate of vibration* that shall be produced (§ 519). The excellence of the instrument depends upon the sonorous character of the wood, which seems to improve with age and use.

(*b.*) Similar remarks apply to the tuning-fork. Hence, for class or lecture experiments, tuning-forks should be mounted as shown in Fig. 269.

Experiment 8.—Support horizontally, between two fixed supports, a soft cotton rope a few yards in length. With a stick, strike the rope near one end a blow from below and a crest will be formed as shown in Fig. 270. Vary the tension of the rope, if necessary, until the crest is easily seen. Notice that the crest, *c*, travels from *A* to *B* where it is reflected back to *A* as a trough, *t*.

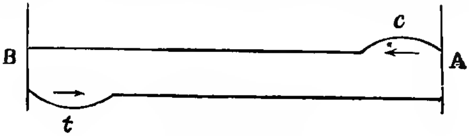


FIG. 270.

By striking the rope from above, a trough may be started which will be reflected as a crest.

Experiment 9.—From *A*, start a trough. At the moment of its reflection as a crest at *B*, start a crest at *A* as shown in Fig. 271. The two crests will meet near the middle of the rope. The crest at the point and moment of meeting results from two forces acting in the same direction, consequently it will be greater than either of the component crests.

FIG. 271.

511. Coincident Waves.—In the case of water waves, when crest coincides with crest the water reaches a greater height. So with sound waves, when condensation coincides with condensation, this part of the wave will be more condensed; when rarefaction coincides with rarefaction, this part of the wave will be more rarefied. This increased difference of density in the two parts of the wave means increased loudness of the sound, because there is an increased amplitude of vibration for the particles constituting the wave.

512. Reinforcement of Sound.—This increased intensity may result from the blending of two or more series of similar waves in like phases, or from the union of direct and reflected waves in like phases. Under such circumstances, one set of waves is said to reinforce the other. *The phenomenon is spoken of as a reinforcement of sound.*

Experiment 10.—Hold a sounding tuning-fork over the mouth of a glass jar, 18 or 20 inches deep; a feeble sound is heard. On carefully pouring in water, we notice that when the liquid reaches a certain level, the sound suddenly becomes much louder. The water has shortened the air column until it is able to vibrate in unison with the fork. If more water be now poured in, the intensity of the sound is lessened. If a fork of different vibration be used, the column of air that gives the maximum resonance will vary, the air column becoming shorter as the rate of vibration of the fork increases. The length of the air column is one-fourth the length of the wave produced by the fork.

FIG. 272.

513. Resonance.—Resonance is a variety of the reinforcement of sound due to sympathetic vibrations. The resonant effects of solids were shown in § 510. The resonance of an air column was well shown by the last experiment.

(*a.*) Fig. 273 represents Savart's bell and resonator. The bell, on being rubbed with the bow, produces a loud tone. The resonator is a tube with a movable bottom. The length of the resonant air column is changed by means of this movable bottom. The point at which the reinforcement of sound is greatest is easily found by trial. If, when the sound of the bell has become hardly audible, the tube be brought near, the resonant effect is very marked.

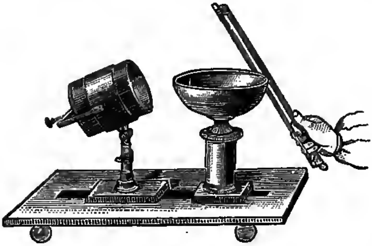


FIG. 273.

514. Helmholtz's Resonators.—Helmholtz, the German physicist, constructed a series of resonators, each one of which resounds powerfully to a single tone of certain pitch or wave length. They are metallic vessels, nearly spherical, having a large opening, as at *A* in Fig. 274, for the admission of the sound waves. The funnel-shaped projection at *B* has a small opening and is inserted in the outer ear of the observer.

FIG. 274.

Experiment 11.—Using the rope as described in Experiment 8, start a crest at *A*. At the moment of its reflection at *B* as a trough, start a second crest at *A*. The trough and crest will meet near the middle of the rope. The rope at this time and place will be urged upward by the crest and downward by the trough. The resultant effect of these opposing forces will, of course, be equal to their difference. If crest and trough exert equal forces, the difference will be zero. Consequently

FIG. 275.

the motion of the rope at the meeting of crest and trough will be little or nothing. *Thus one wave motion may be made to destroy the effect of another wave motion.*

Experiment 12.—Hold a vibrating tuning-fork near the ear and slowly turn it between the fingers. During a single complete rotation, four positions of full sound and four positions of perfect silence will be found. When a side of the fork is parallel to the ear, the sound is plainly audible ; when a corner of a prong is turned toward the ear, *the waves from one prong completely destroy the waves started by the other.* The interference is complete.

Experiment 13.—Over a resonant jar, as shown in Fig. 272, slowly turn a vibrating tuning-fork. In four positions of the fork we have loud, resonant tones ; in four other positions we have complete interference. If, while the fork is in one of these positions of interference, a pasteboard tube be placed around one of the vibrating prongs, a resonant tone is instantly heard ; the cause of the interference has been removed. (Fig. 276.)

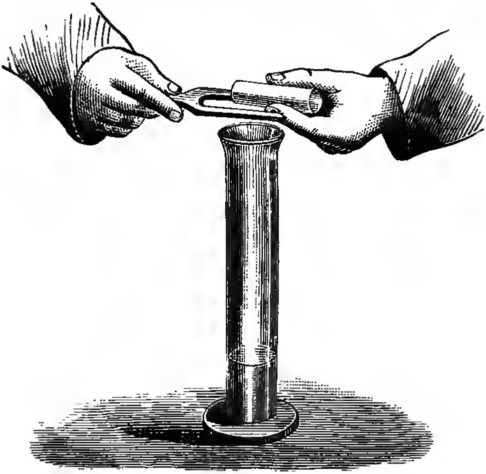


FIG. 276.

515. Interference of Sound.—If, while a tuning-fork is vibrating, a second fork be set in vibration, the waves from the second must traverse the air set in motion by the former. If the waves from the two forks be of equal length, as will be the case when the two forks have the same pitch, and the forks be any number of whole wave lengths apart (Fig. 277), the two sets of waves will unite in like phases (condensation with condensation, etc.), and a reinforcement of sound will ensue. But if the second fork be placed an odd number of half wave lengths behind the other, the two series of waves will meet in opposite phases; where the first fork requires a condensation, the second will require a rarefaction. The two sets of waves will interfere, the one with the other. If the waves be of equal intensity, the algebraic sum of these component forces will be zero. The air particles, thus acted upon, will remain at rest; this means silence. In Fig. 278, an attempt is made to represent this effect to the eye, the uniformity of tint indicating the absence of condensations and rarefactions. *Thus, by adding sound to sound, both may be destroyed. This is the lead-*

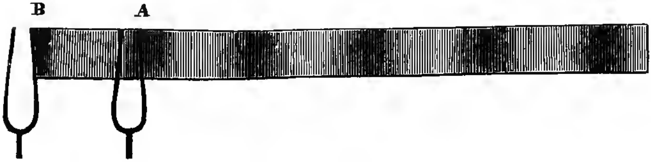


FIG. 277.

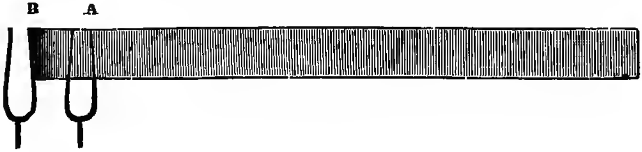


FIG. 278.

ing characteristic property of wave motion. The phenomenon here described is called interference of sound.

(*a.*) The sound of a vibrating tuning-fork held in the hand is almost inaudible. The feebleness results largely from interference. As the prongs always vibrate in opposite directions at the same time, one demands a rarefaction where the other demands a condensation. By covering one vibrating prong with a pasteboard tube, the sound is more easily heard.

Experiment 14.—In a quiet room, strike simultaneously one of the lower white keys of a piano and the adjoining black key. A series of palpitations or *beats* will be heard.

Experiment 15.—Simultaneously sound the two tuning-forks described in Experiment 5, one being loaded as there mentioned; the beats will be very perceptible. Replacing the 3-cent piece successively by a silver half-dime and a dime, the number of beats will be successively increased.

516. Beats.—If two tuning-forks, *A* and *B*, vibrating respectively 255 and 256 times a second, be set in vibration at the same time, their first waves will meet in like phases and the result will be an intensity of sound greater than that of either. After half a second, *B* having gained half a vibration upon *A*, the waves will meet in opposite phases and the sound will be weakened or destroyed. At the end of the second we shall have another reinforcement; at the middle of the next second another interference. *This peculiar palpitating effect is due to a succession of reinforcements and interferences, and is called a beat.* The number of beats per second equals the difference of the two numbers of vibration.

(*a.*) If two large organ pipes, having exactly the same tone, be simultaneously sounded, a low, loud, uniform sound will be produced. If an aperture be made in the upper part of one of the walls of one of the pipes and closed by a movable plate, the tone produced by the pipe may be changed at will. The more the aperture is opened, the higher the pitch. In this manner, *slightly* raise the pitch of one of the pipes. If the pipes be sounded in succession, even a trained ear would probably fail to detect any difference. If they be sounded simultaneously, the sound will be of varying loudness, very marked jerks or palpitations being perceptible.

517. Practical Effect of Beats.—The human ear may recognize about 38,000 different sounds. If a string, for example, vibrating 400 times per second were sounded, and one vibrating 401 times per second were *subsequently* sounded, the ear would probably fail to detect any difference between them. But if they were sounded simultaneously, the presence of one beat each second would clearly indicate the difference. Unaided by the beats, the ear can detect about one per cent. of the 38,000 sounds lying within the range of the human ear. Beats are, therefore, very important to the tuner of musical instruments. To bring two slightly different tones into unison, he has only to tune them so that the beats cease.

518. Vibrations of Strings.—The laws of musical tones are most conveniently studied by means of stringed instruments. In the violin, etc., the strings are set in vibration by bowing them. The hairs of the bow, being rubbed with rosin, adhere to the string and draw it aside until slipping takes place. In springing back, the string is quickly caught again by the bow and the same action repeated. In the harp and guitar, the strings are plucked with the finger. In the piano, the wires are struck by little leather-faced hammers worked by the keys. The vibrations of the string, and consequently the pitch, depend upon the string itself. The manner of producing the vibrations has no effect upon the pitch.

519. Laws of the Vibrations of Strings.—The following are important laws of musical strings:

(1.) Other conditions being the same, the number of vibrations per second varies inversely as the length of the string.

(2.) Other conditions being the same, the number of vibrations per second varies directly as the square root of the stretching weight, or tension.

(3.) Other conditions being the same, the number of vibrations per second varies inversely as the square root of the weight of the string per linear unit.

(*a.*) All of these laws may be roughly illustrated by means of a violin. The length of the string may be altered by fingering; the tension may be changed by means of the screws or keys; the effects of the third law may be shown by the aid of the four strings.

(*b.*) For the illustration of these laws, the sonometer, shown in Fig. 279, is generally used. The length of the string is determined by the two fixed bridges, or by one of them and the movable bridge which may be employed for changing the length of the vibrating part of the string; the tension is regulated by pegs or by weights that may be changed at pleasure; the third law may be verified by using different strings of known weights. Iron and platinum wires of the same diameters are frequently used for this purpose. (Appendix Q.)

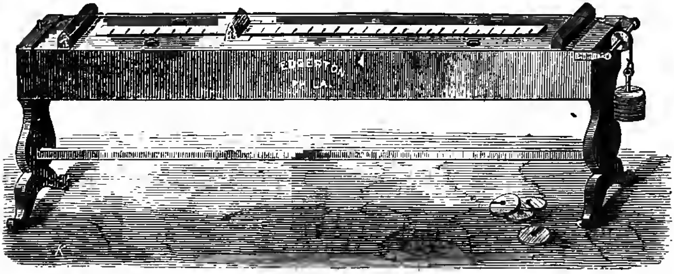
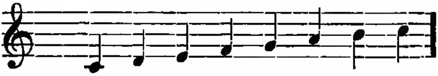


FIG. 279.

(*c.*) From these laws it follows, for example, that a string of half the length, or four times the tension, or one-fourth the weight of a given string will vibrate just twice as fast as the given string, *i.e.*, twice as fast on account of *any one* of these three variations. A string of one-third the length, or nine times the tension, or one ninth the weight of a given string, will vibrate three times as fast as the given string; and so on.

520. The Musical Scale.—Starting from any arbitrary tone or absolute pitch, the voice rises or falls in a manner very pleasing to the ear, by eight steps or intervals. The whole series of musical tones may be divided into octaves, or groups of eight tones each, the relation between any two members of one group being the same as the relation between the corresponding members of any other group. The eighth of the first group becomes the first of the second. The intervals between the successive tones are not the same, as will be seen from the next paragraph.

521. Relative Numbers of Vibrations.—A string vibrating half as rapidly as a given string, will give its octave below; one vibrating twice as rapidly, its octave above. The ratio of the number of vibrations corresponding to the interval of an octave is, therefore, 1:2. The relative number of vibrations corresponding to the tones that constitute the major diatonic scale (gamut) are as follows:

Relative Names,	1,	2,	3,	4,	5,	6,	7,	8.
Absolute Names,	C,	D,	E,	F,	G,	A,	B,	C.
Syllables, -	*do,*	*re,*	*mi,*	*fa,*	*sol,*	*la,*	*si,*	*do.*
Relative Numbers of Vibrations,	1,	$\frac{9}{8}$,	$\frac{5}{4}$,	$\frac{4}{3}$,	$\frac{3}{2}$,	$\frac{5}{3}$,	$\frac{15}{8}$,	2.
" " "	24,	27,	30,	32,	36,	40,	45,	48.

522. Absolute Numbers of Vibrations.—Knowing the number of vibrations that constitute the tone called *do*, the absolute number of vibrations of any of the other tones of the scale may be obtained by multiplying the number of vibrations of *do* by the ratio between it and that of the given tone, as shown above. Thus, if *C* have 256 vibrations per second, *G* will have $256 \times \frac{3}{2} = 384$ vibrations per second; its octave will have 512; the fifth of its octave will have $512 \times \frac{3}{2} = 768$. If *F* be given 352 vibrations, *C* will have $352 \div \frac{4}{3} = 264$. Thus, knowing *C*, any given tone may have its number of vibrations determined by multiplying by the proper ratio.

523. Absolute Pitch.—The number of vibrations constituting the tone called *C* is purely arbitrary. The assignment of 256 complete vibrations to middle *C* is common, but the practice of musicians is not uniform. A certain tuning-fork deposited in the Conservatory of Music at Paris is the standard for France; it assigns 261 vibrations per second to middle *C*. The standard tuning-fork adopted by English musicians and deposited with the Society of Arts in London, gives 264 vibrations to middle *C*. Multiplying the numbers in the last line of § 521 by 11, we shall have the absolute numbers of vibration for the several tones of the gamut corresponding to this standard.

(*a.*) Whatever be the standard thus adopted, an instrument will be in tune when the *relative* number of vibrations is correct. The string that produces the tone *G* must always vibrate three times while the one producing *C* vibrates twice, or 36 times, while the latter vibrates 24 times. While the string yielding *D* vibrates 27 times, the string yielding *B* must vibrate 45 times; and so on.

(*b.*) Middle *C* is the tone sounded by the key of a piano at the left of the two black keys near the middle of the key-board. It is designated by C_1. (See Exp. 16, p. 404.) Its octaves below and above are designated as follows:

$$C_{-2},\quad C_{-1},\quad C,\quad C_1,\quad C_2,\quad C_3,\quad C_4.$$

524. Fundamental Tones and Overtones.—A string may vibrate transversely as a whole, or as independent segments. Such segments will be aliquot parts of the whole string and separated from each other by points of no motion, called nodes or nodal points. *The tone produced by the vibrations of the whole length of a string is called its fundamental tone. The tones produced by the vibrations of the segments of a string are called its overtones or harmonics.*

(*a.*) The fact that a string may thus vibrate in segments, with the further fact that a string, or other sounding body, can hardly be made to vibrate as a whole without vibrating in segments at the same time, furnishes a means of explaining quality or *timbre* of sound. (§ 492.)

525. Fundamental Tones. — When a string vibrates so as to produce its fundamental tone, its extreme positions may be represented by the continuous and the dotted lines of Fig. 280. This effect is obtained by leaving the string free and bowing it near one of its ends. If a number of little strips of paper, doubled in the middle, be placed like riders upon the string, and the string bowed as just described, all of the riders will be thrown up and most of them off. This shows that the whole string vibrates as one string; that there is no part of it between the fixed ends that is not in vibration.

FIG. 280.

526. The First Overtone.—If the string of the sonometer be touched exactly at its middle with a finger, or better, with a feather, a higher tone is produced when the string is bowed. This higher tone is the octave of the fundamental. The string now vibrates in such a way that the point touched remains at rest. Its extreme positions may be represented by the lines of Fig. 281. The point *N* is acted upon by two equal and opposite forces; it is urged to move both

FIG. 281.

ways at the same time and, consequently, does not move at all, but remains at rest as a node. The tone is due to the vibrations of the two halves of the string, which thus give the octave instead of the fundamental. The existence of the node and segments will continue for some time after the finger is removed. If riders be placed at *C*, *N* and *D*, the one at *N* will remain at rest while those at *C* and *D* will probably be dismounted.

527. Higher Overtones.—In like manner, if the vibrating string be touched at exactly one-third, one-fourth or one-fifth of its length from one end, it will divide into three, four or five segments, with vibrations three, four or five times as rapid as the fundamental vibrations. If touched at one-third its length, as represented in Fig. 282, the tone will be the fifth to the octave of the fundamental;

FIG. 282.

if touched at one-fourth its length, the tone will be the second octave above. Of course, any other aliquot part of the length of the string may be used. In any case, the experiment with riders may be repeated to indicate the position of the segments and nodes.

528. Quality or Timbre.—As a sounding body vibrates as a whole and in segments at the same time, the fundamental and the harmonics blend. The resultant effect of this blending of fundamentals and harmonics constitutes what we call the quality or *timbre* of the sound. We recognize the voice of a friend, not by its loudness nor by its pitch, but by its quality. When a piano and violin sound the same tone, we easily distinguish the sound of one from that of the other, because, while the fundamentals are alike, the harmonics are different. Hence, *the total effects* of the fundamentals and the harmonics, or the qualities, are different. The possible combinations of fundamentals and harmonics, or forms of vibratory motion, are innumerable.

Experiment 16.—Take your seat before the key-board of a piano. Press and hold down the key of "middle C," marked 1 in Fig. 283,

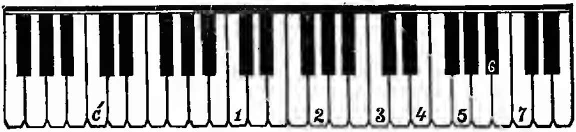


FIG. 283.

which represents part of the key-board. This will lift the damper from the corresponding piano wire and leave it free to vibrate. Strongly strike the key of C', an octave below. Hold this key down for a few-seconds and then remove the finger. The damper will fall upon the vibrating wire and bring it to rest. When the sound of C' has died away, *a sound of higher pitch is heard.* The tone corresponds to the wire of 1, which wire is now vibrating. These vibrations are sympathetic with those that produced the first overtones of the wire that was struck. *These vibrations in the wire of 1 prove the presence of the first overtone in the vibrating wire of C′.* (See § 509.)

In similar manner, successively raise the dampers from the wires of 2, 3, 4, 5, 6 and 7. striking *C′* each time. These wires will accumulate the energy of the waves that correspond to the respective overtones of the wire of *C′* and give forth each its proper tone. *Thus we analyze the sound of the wire of C′ and prove that at least seven overtones are blended with its fundamental.*

Some of these tones of higher pitch, thus produced by *vibrations sympathetic with the vibrations of the segments* of the wire of *C′*, are feebler than others. This shows that the quality of a tone depends upon the relative intensities as well as the number of the overtones that blend with the fundamental.

529. Simple and Compound Tones.—The well trained ear can detect several sounds of different pitch when a single key of a piano is struck. In other words, the sound of a vibrating piano wire is a compound sound. The sound of a tuning-fork is a fairly good example of a simple sound. Simple sounds all have the same quality, differing only in loudness and pitch.

(*a.*) A series of Helmholtz's resonators enables the student of acoustics to analyze any compound sound. Each component tone may be reproduced by a tuning-fork of appropriate pitch. By sounding simultaneously the necessary number of forks, each of proper pitch and with appropriate relative intensity, Helmholtz showed that the sounds of musical instruments, including even the most wonderful one of all (the human voice), may be produced synthetically.

530. Classes of Musical Instruments.—Musical instruments may be divided into two classes, stringed instruments and wind instruments. The sounds sent forth by stringed instruments are due to the regular vibrations of solids; those sent forth by wind instruments, to the regular vibrations of columns of air confined in sonorous tubes.

531. Sonorous Tubes.—The material of which a sonorous tube is made does not affect the pitch or loudness of the sound, but does determine its *timbre* or quality. Sonorous tubes are called mouth pipes or reed pipes, according to the way in which the column of air is made to vibrate.

532. Stopped Pipes.—A sonorous tube may have one end stopped or both ends open. In either case, the tones are due to waves of condensation and rarefaction transmitted through the length of the tube. In a stopped pipe, the air particles at the closed end have no opportunity for vibration; this end of the tube is, therefore, a node. The mouth of the tube affords opportunity for the greatest amplitude. The length of such a pipe is one-fourth the wave length of its fundamental tone.

533. Open Pipes.—In an open pipe, the ends afford opportunity for the greatest amplitude; the node will fall at the middle. The air column will now equal one-half the wave length; the tone will be an octave higher than that produced by a stopped pipe of the same length.

534. Organ Pipes.—The organ pipe affords the best illustration of mouth pipes. Fig. 284 represents the most common kind of organ pipe, which may be of wood or metal, rectangular or cylindrical. The air current from the bellows enters through *P*, passes into a small chamber, emerges through the narrow slit, *i*, and escapes in puffs between *a* and *b*, the two lips of the mouth. The puffs are due to the fact that the air current from *i* strikes upon the bevelled lip, *a*, and breaks into a flutter. The puffing sound thus produced consists of a confused mixture of many faint sounds. The air column of the pipe can resound to only one of these tones. The resonance of the air column, brought about in this way, constitutes the tone of the pipe.

(*a*.) We see, from the above, that it makes little difference how the pulses of air are produced. A vibrating tuning-fork held at the mouth of a pipe of the same pitch is enough to make the pipe sound forth its tone. The production of the tone is strictly analogous to the phenomena mentioned in § 513.

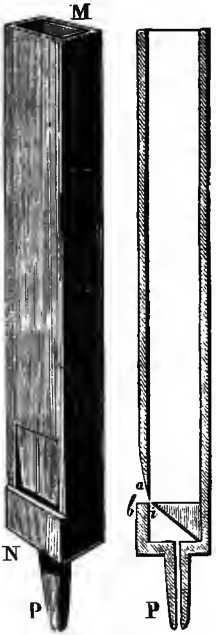


FIG. 284.

535. Reed Pipes.—A simple reed pipe may be made by cutting a piece of wheat straw eight inches (20 *cm*) long so as to have a knot at one end. At *r*, about an inch

FIG. 285.

from the knot, cut inward about a quarter of the straw's diameter; turn the knife-blade flat and draw it toward the knot. The strip, *rr′*, thus raised is a reed; the straw itself is a reed pipe. When the reed is placed in the mouth, the lips firmly closed around the straw between *r* and *s* and the breath driven through the apparatus, the reed vibrates and thus produces vibrations in the air column of the wheaten pipe. Notice the pitch of the musical sound thus produced. Cut off two inches from the end of the pipe at *s*. Blow through the pipe as before and notice that the pitch is raised. Cut off, now, two inches more, and upon sounding the pipe the pitch will be found to be still higher. We thus see that the pipe and not the reed determines the pitch. In these three cases we had the same reed which was obliged to adapt itself to the different vibrations of the different air columns.

(*a*.) It will be easily seen how reeds may be used in musical instruments. The accordeon, clarionet and vocal apparatus are reed instruments.

536. Effect of Lateral Openings. — Certain wind instruments, like the flute, fife and clarionet, have holes in the sides of the tube. On opening one of these holes, opportunity is given for greatest amplitude at that point. This changes the distribution of nodes, affects the length of the segments of the vibrating air columns, and thus determines the wave length or pitch of the tone.

EXERCISES.

1. If a musical sound be due to 144 vibrations, to how many vibrations will its 3d, 5th and octave, respectively, be due?

2. Determine the length of a tube open at both ends that can resound to the tone of a tuning-fork vibrating 512 times a second.

3. A certain string vibrates 100 times a second. (*a*.) Find the number of vibrations of a similar string, twice as long, stretched by the same weight. (*b*.) Of one half as long.

4. A certain string vibrates 100 times per second. Find the number of vibrations of another string that is twice as long and weighs four times as much per foot and is stretched by the same weight.

5. A musical string vibrates 200 times a second. State (*a*) what

takes place when the string is lengthened or shortened with no change of tension, and (*b.*) what change takes place when the tension is made more or less, the length remaining the same.

6. A tube open at both ends is to produce a tone corresponding (*a.*) to 32 vibrations per second. Taking the velocity of sound as 1120 ft., find the length of the tube. (*b.*) If the number of vibrations be 4480, find the length of the tube.

7. (*a.*) Find the length of an organ pipe whose waves are four feet long, the pipe being open at both ends. (*b.*) Find the length, the pipe being closed at one end.

8. A tuning-fork produces a strong resonance when held over a jar 15 inches long. (*a.*) Find the wave length of the fork. (*b.*) Find the wave period.

9. If two tuning-forks vibrating respectively 256 and 259 times per second be simultaneously sounded near each other, what phenomena would follow?

10. A musical string, known to vibrate 400 times a second, gives a certain tone. A second string sounded a moment later seems to give the same tone. When sounded together, two beats per second are noticeable. (*a.*) Are the strings in unison? (*b.*) If not, what is the rate of vibration of the second string?

11. If a tone be produced by 256 vibrations per second, what numbers will correspond to its third, fifth and octave respectively?

12. If a tone be produced by 264 vibrations per second, what number will represent the vibrations of the tone a fifth above its octave.

Recapitulation.—In this section we have considered the Telephone and Phonograph; Sympathetic Vibrations and the Resonance of Sounding Boards and Air Columns; Reinforcement and Interference of superposed waves, including the phenomenon of Beats; Vibrating Strings; The Musical Scale and its relation to Number of Vibrations and Pitch; Timbre and its dependence upon Fundamentals and Harmonics; Simple and Compound Tones, their Synthesis and Analysis; Musical Instruments

REVIEW QUESTIONS AND EXERCISES.

1. (*a.*) Define sound; (*b.*) give its cause; (*c.*) mode of propagation and (*d.*) velocity.

2. (*a.*) Give the rate at which sound is transmitted in air. (*b.*) How is it affected by temperature? (*c.*) Give the law of Reflection. (*d.*) How may it be illustrated?

3. (*a.*) What is capillary attraction? (*b.*) Give three illustrations of the importance of capillary action in the operations of nature.

4. (*a.*) Describe an experiment showing the expansibility of the air. (*b.*) Give the laws of the Pendulum.

5. (*a.*) On what does the loudness of sound depend? (*b.*) How may the pitch of strings be varied? (*c.*) Give the relative number of vibrations in the major diatonic scale and (*d.*) find the number of vibrations for A_2.

6. (*a.*) Represent by a diagram, a lever of the first class, in which one pound will balance five. (*b.*) Give the laws of falling bodies.

7. Explain the Artesian well by a diagram.

8. (*a.*) What will be the momentum of a ball weighing two ounces after falling 4½ seconds? (*b.*) A stone weighing 20 lb. on the surface of the earth, would weigh how much at an elevation of 2000 miles from the surface?

9. Define (*a.*) wave length; (*b.*) wave period; (*c.*) amplitude of vibration; (*d.*) phase of a vibrating particle.

10. (*a.*) What would be the effect of making a small hole at the highest point of a siphon in action? (*b.*) What effect upon the action of a siphon would be produced by carrying it up a mountain? (*c.*) What effect would follow if the atmosphere were suddenly to become denser than the liquid being moved?

11. Describe (*a.*) a complete sound wave and (*b.*) its manner of propagation. (*c.*) How does the transmission of sound through a smooth tube differ from its transmission through the open air?

12. Give the laws for pressure of liquids and explain each by some fact or experiment.

13. (*a.*) Distinguish clearly between noise and music. (*b.*) What is meant by timbre? (*c.*) By pitch?

14. Give three examples of musical sounds that agree in one and differ in two elements or characteristics, making a different element agree each time.

15. Give three examples of musical sounds that differ in one and agree in two elements, making a different element differ each time.

16. (*a.*) What are sympathetic vibrations? (*b.*) How may they be produced? (*c.*) What are beats? (*d.*) How may they be produced?

17. (*a.*) What is Archimedes' Principle? (*b.*) How is it applied in finding the specific gravity of a solid?

18. How much water per hour will be delivered from an orifice of 2 inches area 49 feet below the surface of a tank kept full?

19. Describe the telephone.

20. (*a.*) Describe the electrophorus. (*b.*) Explain its action.

21. (*a.*) Describe an organ pipe. (*b.*) Make a reed pipe.

22. (*a.*) Explain the charging of the Leyden jar; (*b.*) when charged, what is the electric condition of the outside and inside of the jar?

23. (*a.*) A body falls for six seconds; find the distance traversed in the last two seconds of its fall. (*b.*) How far will a body fall in $\frac{1}{10}$ of a second beginning at the end of four seconds? (*c.*) Explain the "kick" of a gun.

24. (*a.*) Show that if, in an Attwood's machine, one weight be $\frac{3}{5}$ as heavy as the other, its increment of velocity will be $\frac{1}{4}$ that of a freely falling body. (*b.*) That if the lighter weight be $\frac{5}{7}$ of the heavier, its increment of velocity will be $\frac{1}{6}\ g$.

25. A telegraph line from New York City to Meadville, Pa., is 510 miles long. The wire has a resistance of 4 ohms per mile. There are, on this line, 19 relays of 150 ohms each and one repeater of 250 ohms. The current is supplied by a series of 40 gravity cells with an E. M. F. of 1 volt each. Suppose that the battery and the ground and other connections offer a resistance of 574 ohms. What is the strength of the current? *Ans.* 7 milliamperes.

26. Explain the electrical phenomena described in § 323 (*b*).

27. An arc lamp has a difference of potential of 36 volts between the carbon tips. The resistance of the arc is 3.6 ohms. (*a.*) What is the current strength? (*b.*) What amount of heat is developed in the arc per second. *Ans.* (*a.*) 10 amperes; (*b.*) 86.4 calories.

28. A coil of fine wire with a resistance of 46.64 ohms was placed in 100 grams of ice-cold water. A current from a series of 50 voltaic cells was sent through the wire for 10 minutes. Each cell had an E. M. F. of 1 volt and a resistance of 6 ohms. [The water would not short circuit the wire. See Appendix K (2)]. (*a.*) What was the current strength? (*b.*) Find the rise of temperature of the water assuming that no heat is lost by the water.

Ans. (*a.*) 0.144 amperes; (*b.*) 1.39° C.

CHAPTER VIII.

HEAT.

SECTION I.

TEMPERATURE, THERMOMETERS, EXPANSION.

537. Introductory Quotation.—"There are other forces besides gravity, and one of the most active of these is chemical affinity. Thus, for instance, an atom of oxygen has a very strong attraction for one of carbon, and we may compare these two atoms to the earth and a stone lodged upon the top of a house. Within certain limits, this attraction is intensly powerful, so that when an atom of carbon and one of oxygen have been separated from each other, we have a species of energy of position just as truly as when a stone has been separated from the earth. Thus by having a large quantity of oxygen and a large quantity of carbon in separate states, we are in possession of a large store of *energy* of position. When we allowed the stone and the earth to rush together, the *energy* of position was transformed into that of actual motion (§ 159), and we should therefore expect something similar to happen when the separated carbon and oxygen are allowed to rush together. This takes place when we burn coal in our fires, and the primary result, as far as *energy* is concerned, is the production of a large amount of heat. We are, therefore, led to conjecture that heat may denote a motion of particles on the small scale just as the rushing together of the stone and the earth denotes a motion on the large. It thus appears that we may have invisible molecular *energy* as well as visible mechanical *energy*."—*Balfour Stewart.*

538. What is Heat?—*Heat is a form of energy. It consists of vibratory motions of the molecules of matter or results from such motions, and* *gives rise to the well known sensations of warmth and cold.* By means of these effects upon the animal body it is generally recognized. Being a form of energy, it is a measurable quantity but not a material substance.

539. What is Temperature?—*The temperature of a body is its state considered with reference to its ability to communicate heat to other bodies.* It is a term used to indicate how hot or cold a body is. When a body receives heat its temperature generally rises, but sometimes a change of condition (§ 53) results instead. When a body gives up heat, its temperature falls or its physical condition changes.

540. An Unsafe Standard.—When we put a very warm hand into water at the ordinary temperature, we say that the water is cold. If another person should put a very cold hand into the same water he would say that the water is warm. If a person place one hand in water freezing cold and the other hand in water as hot as he can endure, and, after holding them there some time, plunge them simultaneously into water at the ordinary temperature, the hand from the cold water feels warm while the hand from the hot water feels cold. These experiments show that bodily sensations cannot be trusted to measure this form of energy that we call heat.

541. Thermometers. — *An instrument for measuring temperature is called a thermometer.* The mercury thermometer is the most common. Its action depends upon the facts that heat expands mercury more than it does glass, and that when two bodies of different temperatures are brought into contact, the warmer one will give heat to the colder one until they have a common temperature.

542. Graduation of Thermometers.—Thermometers are graduated in different ways, but in all cases there are two fixed points, viz., the freezing and the boiling points of water; or, more accurately, the temperature of melting ice and the temperature of steam as it escapes from water boiling under a pressure of one atmosphere.

543. Determination of the Freezing Point.—Ice in contact with water cannot be raised above a certain temperature; water in contact with ice cannot be reduced below the same temperature. Here, then, is a temperature fixed and easily produced. The thermometer is placed in melting ice or snow contained in a perforated vessel. When the mercury column has come to rest, a mark is made on the glass tube at the level of the mercury. This point is, for the sake of brevity, called the freezing point.

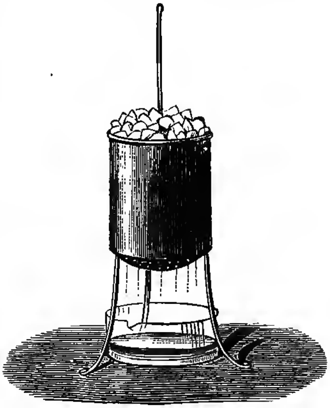


FIG. 286.

544. Determination of the Boiling Point.—The temperature of steam issuing from water boiling under any given pressure is invariable. Fig. 287 represents a metal vessel in which water is made to boil briskly. The thermometer being supported as represented is surrounded by the steam but does not touch the water. That the steam may not cool before it comes into contact with the thermometer, the sides of the vessel are surrounded by what is called a "steam-jacket." A bent tube open at both ends and containing mercury in the bend is sometimes added. When the mercury stands at the same level in both arms, the pressure upon the surface of the boiling liquid is just equal to the external atmospheric pressure, which should be 760 *mm.* When the mercury column has come to rest, a mark is made on the glass tube at the level of the mercury. This point is, for the sake of brevity, called the boiling point.

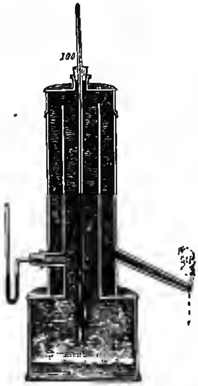


FIG. 287.

FIG. 288.

545. Thermometric Scales.—There are two scales used in this country, the centigrade and Fahrenheit's. For these scales, the fixed points, determined as just explained, are marked as follows:

	Centigrade.	*Fahrenheit.*
Freezing point,	0°	32°
Boiling point,	100°	212°

The tube between these two points is divided into 100 equal parts for the centigrade scale and into 180 for Fahrenheit's. Hence a change of temperature of 5° C. is equal to a change of 9° F., or an interval of one centigrade degree is equal to an interval of $\frac{9}{5}$ of a Fahrenheit degree.

546. Thermometric Readings.—To change the readings of a centigrade thermometer to those of Fahrenheit's, or *vice versa*, is a little more complicated than to determine the relation between the intervals of temperature. This complication arises from the fact that Fahrenheit's *zero* is not at the freezing point but 32 degrees below. To reduce Fahrenheit readings to centigrade readings, subtract 32 from the number of Fahrenheit degrees and multiply the remainder by $\frac{5}{9}$.

$$C. = \frac{5}{9}\,(F. - 32).$$

To reduce centigrade readings to Fahrenheit readings, multiply the number of centigrade degrees by $\frac{9}{5}$ and add 32.

$$F. = \frac{9}{5}\,C. + 32.$$

(*a.*) Suppose that we desire to find the equivalent centigrade reading for 50° F. Subtracting 32, we see that this temperature is 18 Fahrenheit degrees above the freezing point. But one Fahrenheit degree being equal to $\frac{5}{9}$ of a centigrade degree, this temperature is $\frac{5}{9}$ of 18, or 10 centigrade degrees above the freezing point. Hence the reading will be 10° C.

(*b.*) Suppose that we desire to find the equivalent Fahrenheit reading for 45° C. This temperature is 45 centigrade degrees above the freezing point, or 81 Fahrenheit degrees above the freezing point. Hence the reading will be (81 + 32 =) 113° F. (See Fig. 288.)

(*c.*) The centigrade thermometer is the most convenient and is adopted in all countries as the standard scale for scientific reference. Like the metric system, its general use in this country is probably only a question of time.

Note.—It is desirable that this class be provided with several "chemical" thermometers; *i. e.*, thermometers having the scale marked on the glass tube instead of a metal frame.

547. Differential Thermometer.—Leslie's differential thermometer (Fig. 289) shows the difference in temperature of two neighboring places by the expansion of air in one of two bulbs. These bulbs are connected by a bent glass tube containing some liquid not easily volatile. It is an instrument of simple construction (See Appendix, M.) and great delicacy of action, but has been largely superseded by the thermopile and galvanometer (§§ 414, 391).

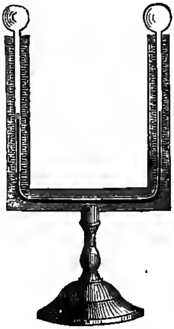


FIG. 289.

548. Expansion.—Heat consists generally of molecular vibrations. Whatever raises the temperature of a body increases the energy with which the molecules of that body swing to and fro. These molecules are too small (§ 5), and their range of motion too minute to be visible, and we must call upon our imaginations to make good the defect of our senses. We must conceive these invisible molecules as held together by the force of cohesion, yet vibrating to and fro. The more intense the heat, the greater the energy of these molecular motions. Molecules thus vibrating must push each other further apart, and thus cause the body which they constitute *to expand.* This expansion, or increase of volume, is the first effect of heat upon bodies.

(*a.*) Imagine, if possible, twenty-five quiet boys standing closely crowded together. Upon the floor draw a chalk line enclosing the group. If these boys be suddenly set shaking, as by the ague, they will force some of their number over the chalk line. From the motions of the individuals has resulted an expansion of the living mass.

549. Expansion Illustrated.—The expansion of solids may be shown by a ball, which, at ordinary temperatures, will easily pass through a ring; on heating the ball it will no longer pass through the ring. If the ball be cooled by plunging it into cold water, it will again pass through the ring. This illustrates the increase of volume or cubical expansion. Sometimes the expansion in length only is measured. This is called linear expansion. Expansion is also illustrated in the compensation pendulum (§ 149).

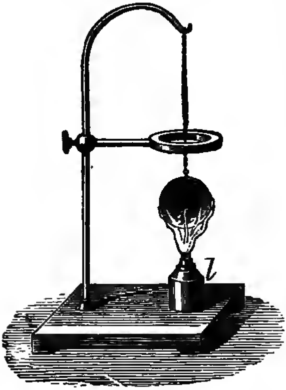


FIG. 290.

550. Unequal Expansion.—Different substances expand at different rates for the same change of temperature. This may be shown by heating a bar made by riveting together, side by side, two thin bars of equal size, one of iron and one of brass, so that the compound bar shall be straight at the ordinary temperature. As brass expands and contracts more than iron, when the compound bar is heated it will curve with the brass on the convex side; when it is cooled, it will curve with the brass on the concave side.

(*a*.) Glass and platinum expand nearly alike. In fact, the rates of expansion are so nearly alike that platinum wires may be *fused* into glass tubes, as is done in electrolysis apparatus and eudiometers. If we attempt thus to fuse copper wire into glass, the glass will be broken during the unequal contraction from cooling.

551. Practical Applications of Expansion.—The energy of expansion and contraction of solids, when heating and cooling, is remarkable. This expansion of metals by heat is utilized by coopers in setting hoops, by wheelwrights in setting tires, and by builders in straightening bulging walls. When the iron rails of our railways are laid, a small space is left between the ends of each two adjoining rails to provide for their inevitable expansion by the summer heat. The iron tubular bridge over the Menai Straits is about 1800 feet long. Its linear expansion is about one foot, and is provided for by placing the ends of the huge tube upon rollers.

552. Expansion of Liquids.—The expansion of liquids may be illustrated as follows: Nearly fill a Florence flask with water, and place it on a retort stand or other convenient support. A long straw is supported by a thread tied near one end. From the short end of this straw lever is suspended a weight nearly balanced by the long arm of the lever. This weight hangs in the neck of the flask, and rests lightly upon the surface of the water (§ 238). By placing a spirit-lamp below the flask the water may be heated. As it expands, it rises in the neck of the flask, raises the weight, and lowers the end of the long arm of the lever, which may be seen to move.

553. Anomalous Expansion of Water.—Water presents a remarkable exception to the general rule. *If water at* 0°C. *be heated, it will contract until it* *reaches* 4° C., *its temperature of greatest density. Heated above this point it expands.*

(*a.*) Through the cork of a large flask pass a fine glass tube. Fill the flask with water at the ordinary temperature, and insert the cork and tube so that the water shall rise some distance in the tube. Place the flask in a freezing mixture, such as salt and pounded ice. The water column in the tube falls, showing that the water is contracting. But before the water freezes the contraction ceases, the column in the tube becomes stationary, and then begins to rise again. This shows that water does not contract on being cooled below a certain temperature, and that there is a temperature of maximum density above the freezing point.

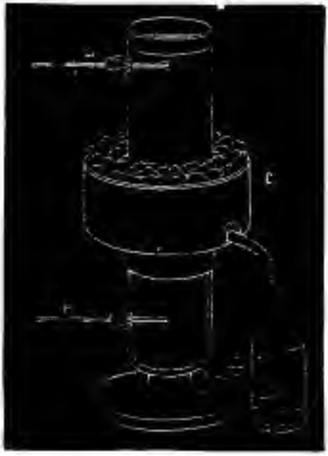


FIG. 291.

(*b.*) Fig. 291 represents a glass cylinder with two thermometers inserted in the side, near the top and bottom, at *A* and *B*. Midway between *A* and *B* is an envelope *C*, which may be filled with a freezing mixture. The envelope being empty, the cylinder is filled with water at 0° C., and placed in a room at the ordinary temperature, about 15° C. As the water molecules at the side of the cylinder become warm, they fall, and *B* soon records a temperature of 4° C., while *A* remains at 0°. This shows that the warm water falls to the bottom. It falls because it is denser. It is denser because it has been *contracted by heat.*

If the experiment be varied by filling the cylinder with water at the ordinary temperature, and *C* with a freezing mixture, the temperature at *B* will fall rapidly, while it falls slowly at *A*. This will continue until *A* reaches 4° C., when *A* begins to fall more rapidly, and continues to do so until it reaches 0°. These experiments show that water is heavier at 4°C. than at any temperature above or below.

554. Results of this Exception.—This property of water is of great importance. Were it otherwise, the ice would sink and destroy everything living in the water. The entire body of water would soon become a solid mass which the heat of summer could not wholly melt, for, as we shall soon see, water has little power to carry heat downward. As it is, in even the coldest winters, the mass of water in our northern lakes remains at a temperature of 4°C., the colder water floats upon the warmer layer, ice forms over all, and protects the living things below.

555. Expansion of Gases.—The expansion of gases may be shown by partly filling a bladder with cold air, tying up the opening, and placing the bladder near the fire. The expanded air will fill the bladder. Through the cork of a bottle pass a small glass tube about a foot long. Warm the bottle a little between the hands and place a drop of ink at the end of the tube. As the air contracts the ink will move down the tube and form a frictionless liquid index. By heating or cooling the bottle the index may be made to move up or down. If a closed flask having a delivery tube terminating under water be heated, some of the expanded air will be forced to escape, and may be seen bubbling through the water. By "collecting over water" the air thus driven out, it may be accurately measured. (Fig. 292.)

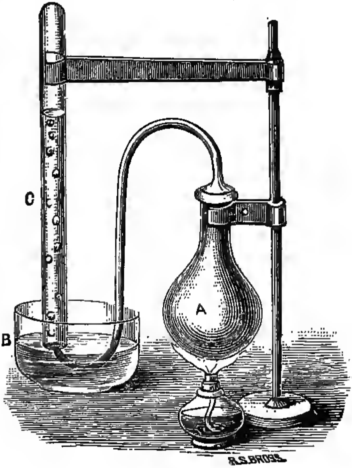


FIG. 292.

556. Practical Results.—The ascension of "fire-balloons" and the draft of chimneys are due to the expansion of gases by heat. When the air in the chimney of a stove or lamp is heated, it is rendered lighter than the same bulk of surrounding air, and, therefore, rises. The cooler air comes in to take its place and thus feeds the combustion. Sometimes when a fire is first lighted, the chimney is so cold that the current is not quickly established and the smoke escapes into the room. But in a little while the air column rises and the usual action takes place. By the aid of a good thermometer it may be shown that the air near the ceiling of a room is warmer than the air near the floor. When the door of a warmed room is left slightly ajar, there will be an inward current near the floor and an outward current near the top of the door. These currents may be shown by holding a lighted candle at these places. Artificial ventilation depends upon the same principles.

557. Rate of Gaseous Expansion.—The rate of expansion is practically the same for all gases, viz., 0.00366 or $\frac{1}{273}$ of the volume at 0° C., for each centigrade degree that the temperature is raised above the freezing point. In other words, a liter of air at 0° C., expands to

$1\ l. + .00366\ l.$ at 1° C.,
$1\ l. + (.00366 \times 2)\ l.$ at 2° C.
$1\ l. + (.00366 \times 3)\ l.$ at 3° C.,
$1\frac{4}{273}\ l.$ at 4° C.

Of course, if we use Fahrenheit degrees the expansion will be only $\frac{5}{9}$ as great, or about $\frac{1}{490}$. A litre of gas at 32° F. expands to $1\frac{1}{490}\ l.$ at 33° F.; to $\frac{497}{490}\ l.$ at 39° F., etc.

558. Absolute Zero of Temperature.—*The temperature at which the molecular motions constituting heat wholly cease is called the absolute zero.* It has never been reached, and has been only approximately determined, but it is convenient as an ideal starting-point. The zero point of the thermometers does not indicate the total absence of heat. A Fahrenheit thermometer, therefore, does not indicate that boiling water is 212 times as hot as ice at 1° F.; a centigrade thermometer does not indicate that boiling water has 100 times as much heat as water at 1° C.

(*a.*) Temperature, when reckoned from the absolute zero, is called absolute temperature. Absolute temperatures are obtained by adding 460 to the reading of a Fahrenheit thermometer, or 273 to the reading of a centigrade thermometer.

559. Temperature, Volume and Pressure.—

By raising a gas from 0° C. to 273° C., its volume will be doubled. To reduce the gas at this temperature to its original volume, the original pressure must be doubled. From our knowledge of pneumatics and gaseous expansion, we are able to solve certain problems relating to the volume of gases under different pressures and temperatures.

Examples.—(1.) A mass of air at 0° C. and under an atmospheric pressure of 30 inches, measures 100 cu. inches; what will be its volume at 40° C. under a pressure of 28 inches? First, suppose the pressure to change from 30 inches to 28 inches. The air will expand, the two volumes being in the ratio of 28 to 30 (§ 284). In other words, the volume will be $\frac{30}{28}$ times 100 cubic inches or $107\frac{1}{7}$ cu. in. Next, suppose the temperature to change from 0° C. to 40° C. The *expansion* will be $\frac{40}{273}$ of the volume at 0° C.; the *volume* will be $1\frac{40}{273}$ of the volume at 0° C. $1\frac{40}{273}$ times $107\frac{1}{7}$ cubic inches $=122\frac{586}{637}$ inches.—*Ans.*

The problem may be worked by proportion as follows:

$$\left.\begin{array}{r} 28 : 30 \\ 1 : 1\frac{40}{273} \end{array}\right\} :: 100 : x. \qquad \text{or} \left.\begin{array}{r} 28 : 30 \\ \frac{273}{273} : \frac{313}{273} \end{array}\right\} :: 100 : x.$$

$$\text{or} \left.\begin{array}{c} 28 : 30 \\ 273 : 273 + 40 \end{array}\right\} 100 : x. \qquad \therefore x = 122.84 + \text{cu. in.}$$

(2.) At 150° C., what will be the volume of a gas that measures 10 *cu. cm.* at 15° C.?

$$273 + 15 : 273 + 150 :: 10 : x. \qquad \therefore x = 14.69 \textit{ cu. cm.}$$

(3.) If 100 *cu. cm.* of hydrogen be measured at 100° C., what will be the volume of the gas at −100° C.?

$$273 + 100 : 273 - 100 :: 100 : x. \qquad \therefore x = 46.37 \textit{ cu. cm.}$$

(4.) A liter of air is measured at 0° C. and 760 *mm.* What volume will it occupy at 740 *mm.*, and 15.5° C.?

$$\left.\begin{array}{l} 273 : 273 + 15.5 \\ 740 : 760 \end{array}\right\} :: 1{,}000 : x. \qquad \therefore x = 1085.34 \textit{ cu. cm.}$$

EXERCISES.

1. A rubber balloon, capacity of 1 liter, contains 900 *cu. cm.* of oxygen at 0° C. When heated to 30° C., what will be the volume of the oxygen? *Ans.* 998.9 *cu. cm.*

2. If 170 volumes of carbonic acid gas be measured at 10° C., what will be the volume when the temperature sinks to 0° C.?

3. A certain weight of air measures a liter at 0° C. How much will the air expand on being heated to 100° C.? *Ans.* 1,366.3 *cu. cm.*

4. A gas has its temperature raised from 15° C. to 50° C. At the latter temperature it measures 15 liters. What was its original volume? *Ans.* 13,374.6 *cu. cm.*

5. A gas measures 98 *cu. cm.* at 185° F. What will it measure at 10° C. under the same pressure? *Ans.* 77.4 *cu. cm.*

6. To what volume will a liter of gas contract in cooling from 42° F. to 32° F.? *Ans.* 980 *cu. cm.*

7. A certain quantity of gas measures 155 *cu. cm.* at 10° C., and under a barometric pressure of 530 *mm.* What will be the volume at 18.7° C., and under a barometric pressure of 590 *mm.*?

8. A gallon of air (231 cu. in.) is heated, under constant pressure, from 0° C. to 60° C. What was the volume of the air at the latter temperature? *Ans.* 281.7 cu. in.

9. A fire balloon contains 20 cu. ft. of air. The temperature of the atmosphere being 15° C. and that of the heated air in the balloon being 75° C., what weight, including the balloon, may be thus supported? (See Appendix G.) *Ans.* 1,847 grains.

10. The difference between the temperatures of two bodies is 36° F. Express the difference in centigrade degrees.

11. The difference between the temperatures of two bodies is 35° C. Express the difference in Fahrenheit degrees.

12. (*a.*) Express the temperature 68° F. in the centigrade scale. (*b.*) Express the temperature 20° C. in the Fahrenheit scale.

13. What will be the tension at 30° C. of a quantity of gas which at 0° C. has a tension of a million dynes per *sq. cm.*, the volume remaining the same? (§ 69.) *Ans.* 1109800 dynes.

14. A liter of gas under a pressure of 1013600 dynes per *sq. cm.* is allowed to expand until the pressure is reduced to 1000000 dynes per *sq. cm.* At the same time, the temperature is raised from 0° C to 100° C. Find the final volume. *Ans.* 1385 *cu. cm.* nearly.

Recapitulation.—In this section we have considered the Nature of Heat; the meaning of Temperature; Thermometers and their graduation; the determination of the Freezing and Boiling Points; thermometric Scales and Readings; the Differential Thermometer; Expansion of Solids; Expansion of Liquids, especially the Expansion of Water; the Expansion of Gases and the Rate thereof; Absolute Zero of temperature; the relation between Temperature, Pressure and Volume.

SECTION II.

LIQUEFACTION, VAPORIZATION, DISTILLATION.

560. Liquefaction.—In the last section we learned that heat is a form of energy. As energy, it is able to perform work, such as overcoming or weakening the force of cohesion. It is well known that when a solid is changed to the liquid or aëriform condition, or when a liquid is changed to a vapor, it is done by an increase of heat, and that when the reverse operations are performed, it is by a diminution of heat. Cohesion draws the particles together; heat pushes them asunder, and on the varying preponderance of one or the other of these antagonistic powers, the condition of the body seems to depend. When the firm grip of cohesion has been so far weakened by heat that the molecules easily change their relative positions (§ 55), the body passes from the solid into the liquid condition. This change of condition is called liquefaction.

561. Laws of Fusion.—It has been found by experiment that the following statements are true:

(1.) Every solid begins to melt at a certain temperature which is invariable for the given substance if the pressure be constant. When cooling, the substance will solidify at the temperature of fusion.

(2.) The temperature of the solid, or liquid, remains at the melting point from the moment that fusion or solidification begins until it is complete.

(*a.*) If a flask containing ice be placed over a fire, it will be found that the hotter the fire the more rapid the liquefaction, but that if the contents of the flask be continually stirred, the thermometer will remain at 0° C. until the last bit of ice is melted (§ 543). If sulphur be used instead of ice, the temperature will remain at 115° C. until the sulphur is all melted. (Fig. 293.)

FIG. 293.

562. Reference Table of Melting Points:

Alcohol,	Never frozen.
Mercury,	—38.8°C.
Sulphuric acid,	—34.4
Ice,	0.
Sulphur,	115.
Lead,	326
Zinc,	425
Silver (pure),	1,000
Gold (pure),	1,250
Iron (wrought),	1,600

Note.—The higher temperatures in this table are only approximate. Certain bodies soften and become plastic before they melt. In this condition glass is worked and iron is welded.

563. Vaporization.—If, after liquefaction, further additions of heat be made, a point will be reached at which the heat will overbalance both the cohesion and the pressure of the atmosphere and the liquid pass into the aëriform condition. This change of form is called vaporization. Vaporization may be of two kinds—evaporation and ebullition.

564. Evaporation.—*Evaporation signifies the quiet formation of vapor at the surface of a liquid.*

(*a.*) With reference to the rapidity with which evaporation takes place, it may be remarked that—

(1.) It varies with the temperature.
(2.) It varies with the extent of surface.
(3.) It varies with pressure upon the liquid, being exceedingly rapid in a vacuum.

565. Evaporation in Vacuo.—The rapid formation of vapors in a vacuum is prettily illustrated by the following experiment: Torricellian vacua are formed at the top of four barometer tubes, *A*, *B*, *C* and *D*, Fig. 294. Into the mouth of *B* pass a few drops of water. They will rise through the mercury to the vacuum at the top. Upon reaching this open space they are *instantly vaporized.* The tension of the aqueous vapor shows itself by lowering the mercury column. This depression is due to the tension rather than to the weight of the vapor, because the water weighs scarcely anything compared with the mer

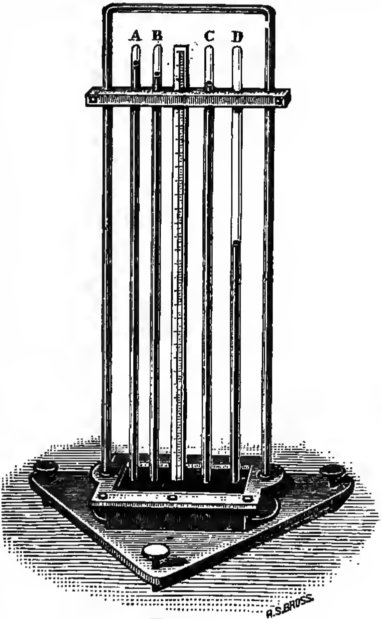


FIG. 294.

cury it displaces. Introducing the same quantity of alcohol into *C*, and of ether into *D*, they are instantly vaporized, but the mercury will be depressed more by the alcohol than by the water, and more by the ether than by the alcohol.

(*a.*) At the beginning of the experiment, the four mercury columns indicated the atmospheric pressure; at the end of the experiment, the column in *A* indicated the full pressure of the atmosphere; the columns in *B*, *C* and *D* indicate that pressure *minus* the tension of their respective vapors. This experiment also shows that, *at the same temperature, the vapors of different liquids have different tensions.*

566. Ebullition.—*Ebullition, or boiling, signifies the rapid formation of vapor bubbles in the mass of a liquid.* When a flask containing water is placed over the flame of a lamp, the absorbed air that is generally to be found in water is driven off in minute bubbles that rise and escape without noise. As the temperature of the water is raised, the liquid molecules in contact with the bottom of the flask become so hot that the heat is able to overcome the cohesion between the molecules, the pressure

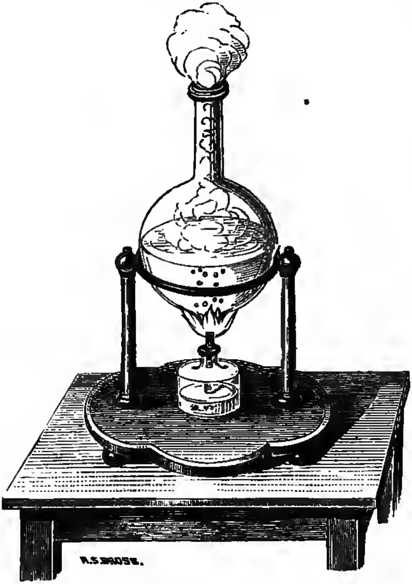


FIG. 295.

of the overlying water, and the pressure of the atmosphere above the water. Then the water boils.

(*a.*) When the first bubbles of steam are formed at the bottom of the water, they rise through the water, condense in the cooler layers above, and disappear before reaching the surface. The formation and condensation of these bubbles produce the peculiar sound known as *singing* or *simmering*, the well-known herald of ebullition. Finally, the water becomes heated throughout, the bubbles increase in number, grow larger as they ascend, burst at the surface, and disappear in the atmosphere. The whole liquid mass is agitated with considerable vehemence, there is a characteristic noisy accompaniment, the quantity of water in the flask diminishes with every bubble, and finally it all disappears as steam. The water has "boiled away."

567. Laws of Ebullition.—It has been found by experiment that the following statements are true:

(1.) Every liquid begins to boil at a certain temperature, which is invariable for the given substance if the pressure be constant. When cooling, the substance will liquefy at the temperature of ebullition, or at the boiling point.

(2.) The temperature of the liquid, or vapor, remains at the boiling point from the moment that it begins to boil or liquefy.

(3.) An increase of pressure raises the boiling point; a decrease of pressure lowers the boiling point.

FIG. 296.

(*a.*) In a beaker half full of water, place a thermometer and a test tube half filled with ether. Heat the water. When the thermometer shows a temperature of about 60° C., the ether will begin to boil. The water will not boil until the temperature rises to 100° C. The temperature will not rise beyond this point.

568. Vapor Pressure.—The pressure of a vapor (§ 282) is due to the kinetic energy of its constituent molecules. "As a liquid evaporates in a closed space, the vapor formed exerts a pressure upon the enclosure and upon the surface of the liquid, which increases as long as the quantity of vapor increases and reaches a maximum when the space is saturated. This maximum pressure of a vapor increases with the temperature. When evaporation takes place in a space filled by another gas that has no action upon the vapor, the pressure of the vapor is added to that of the gas and the pressure of the mixture is, therefore, the sum of the pressures of its constituents."

569. Effect of Pressure upon Boiling Point.—We saw in § 566 that when a liquid is boiled, the heat has three tasks or three kinds of work to perform, viz., overcoming cohesion, liquid and atmospheric pressures. Nothing can be more evident than the propositions that increasing the work to be done involves an increase in the energy needed to do the work; that decreasing the work to be done involves a decrease in the energy needed to do the work. In the case of boiling any given liquid, the first of the three tasks can not be varied; either of the other two easily may. If we increase the pressure, we increase the work to be done and, therefore, increase the necessary amount of heat, the only form of energy competent to do the work. If we lower the pressure, we lessen the work to be done and, therefore, lessen the necessary amount of heat. This means, in the first case, raising the boiling point; in the second case, lowering the boiling point.

570. Franklin's Experiment.—The boiling of water at a temperature below 100° C. may be shown as follows: Half fill a Florence flask with water. Boil the water until the steam drives the air from the upper part of the flask. Cork tightly, remove the lamp and invert the flask. The exclusion of the air may be made more certain by immersing the corked neck of the flask in water that has been recently boiled. When the lamp was removed, the temperature was not above 100° C. By the time that the flask is inverted and the boiling has ceased, the temperature will have fallen below 100° C. When the boiling stops, pour cold water upon the flask; directly the boiling begins again.


FIG. 297.

(*a*.) The cold water poured upon the flask lowers the temperature of the water in the flask still further, but it also condenses some of the steam in the flask or reduces its tension (§ 559). This reduction of the tension lessens the work necessary to boiling. There being enough heat in the water to do this lessened amount of work, the water again boils and increases the pressure until the boiling point is raised above the present temperature of the water. The flask may be drenched and the water made to boil a dozen times in succession with a single heating. The experiment may be made more striking by plunging the whole flask under cool water.

571. Papin's Digester.—At high elevations water boils at a temperature too low for culinary purposes. Persons living there are obliged to boil meats and vegetables (if at all) in closed vessels and under a pressure greater than that of the atmosphere. In the arts, a higher temperature than 100° C. is sometimes required for water, as, for example, in the extraction of gelatine from bones. In a closed vessel, water may be raised to a much higher temperature than in the open air, but, for reasons now obvious, water cannot be kept boiling in such a vessel. Papin's Digester consists of a metal vessel of great strength covered with a lid pressed down by a powerful screw. That the joint may be more perfect, a ring of sheet lead is placed between the edges of the cover and of the vessel. It is provided with a safety valve, pressed close by a loaded lever. When the tension of the steam reaches a dangerous point, it opens the valve, lifting the weight and thus allowing some of the steam to escape.

(*a.*) In many cases, *e. g.*, sugar refining, it is desirable to boil or evaporate a liquid at as low a temperature as possible. The work is then done in a *vacuum pan* from which the vapor is pumped, the tension being thus reduced.

572. Marcet's Globe.—Marcet's globe is represented in Fig. 298. It consists of a spherical metallic boiler, five or six inches in diameter, provided with three openings through one of which a thermometer, *T*, passes; through the second of which a glass manometer tube, *M*, passes; the third opening being provided with a stop-cock, *S*. The thermometer and manometer tubes fit their openings so closely that no steam can escape at those points. The thermometer bulb is exposed directly to the steam. The lower end of the manometer tube dips into mercury placed in the lower part of the globe. The boiler is to be half filled with water and heated until the water boils, the stop-cock being open. As long as the stop-cock is open, the thermometer will not rise above 100° C. When the stop-cock is closed, the steam accumulates, the pressure on the water increases, the thermometer shows a rise of temperature beyond 100° C. higher and higher as the mercury rises in the manometer tube.

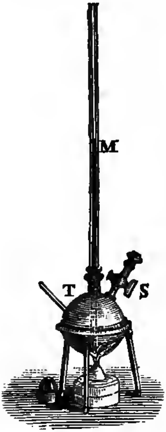


FIG. 298.

When the mercury in the manometer tube is 760 *mm.* above the level of the mercury in the boiler, the steam has a tension of two atmospheres, and the thermometer will record a temperature of about 121° C.

573. Concerning Steam.—*A given mass of water in the aeriform condition occupies nearly 1700 times as much space under a pressure of one atmosphere as it does in the liquid condition.* In other words, a cubic inch of water will yield nearly a cubic foot of steam. *Steam is invisible.* What is commonly called steam is not true steam, but little globules of water condensed by the cold air and suspended in it. By carefully noticing the steam issuing from the spout of a tea-kettle, it will be observed that for about an inch from the spout there is nothing visible. The steam there has not had opportunity for condensation. The water particles visible beyond this space passed through it as invisible steam. The steam in the flask of Fig. 297 is invisible.

574. Reference Tables.—Boiling Points under a pressure of one atmosphere:

Ammonia	−40° C.	Alcohol	78° C.
Sulphurous anhydride	− 8	Water (pure)	100
Ether	35	Mercury	350
Carbon bisulphide	48	Sulphur	447

Some solids, as iodine, arsenic and camphor vaporize without visible intermediate liquefaction. The process is called *sublimation.*

Boiling Points of water at different pressures:

Thermometer.	*Barometer.*	*Thermometer.*	*Atmospheres.*
184° F.	16.676 inches.	212° F.	1
190°	18.992	249.5	2
200	23.454	273.3	3
210	28.744	318.2	6
212	29.922	356.6	10
215	31.730	415.4	20

575. Definition of Boiling Point.—We ought now to be fully prepared to understand that *the boiling point of a liquid is the temperature at which it gives off a vapor of the same tension as the surrounding atmosphere.*

(*a.*) If there be any doubt or lack of comprehension of this proposition, it may be removed by the following experiment: A glass tube, bent as shown at *A*, has its short arm closed and its long arm open. The short arm is nearly filled with mercury, the space above the mercury being filled with water. While water is briskly boiling in a flask, the bent tube is suspended in the steam, as shown in Fig. 299. Part of the water in the bent tube is changed to vapor, the mercury falls in the short arm, and finally *assumes the same level in both branches.*

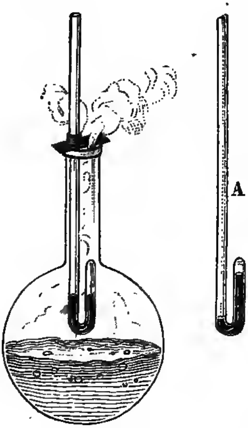


FIG. 299.

576. Distillation.—Distillation is a process of separating a liquid from a solid which it holds in solution, or of separating a mixture of two liquids having different boiling points. The process depends upon the fact that different substances are vaporized at different temperatures. The apparatus, called a still, is made in many forms, but consists essentially of two parts—the retort for producing vaporization, and a condenser for changing the vapor back to the liquid form. Fig. 300 represents one form of the apparatus. It consists of a retort, *ab*, the neck of which is connected with a spiral tube, *dd*, called *the worm.* The worm is placed in a vessel containing water. This vessel is continually fed with cold water carried to the bottom by the tube *h*. As the water is warmed by the worm it rises and overflows at *i*.

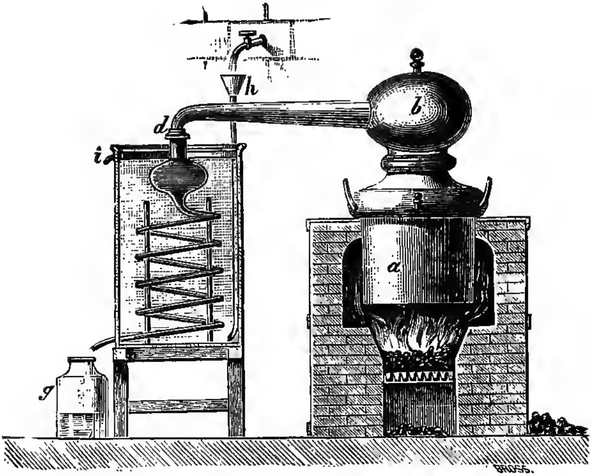


FIG. 300.

577. Distillation of a Liquid from a Solid.—Suppose that water is to be separated from the salt it holds in solution. The brine is placed in a retort and heated a little above 212° F. At this temperature the water is vaporized while the salt is not. The steam is driven from the retort through the worm, where it is rapidly condensed and passes into a vessel prepared to receive it. The salt remains in the retort. Of course, the water of the vessel containing the worm

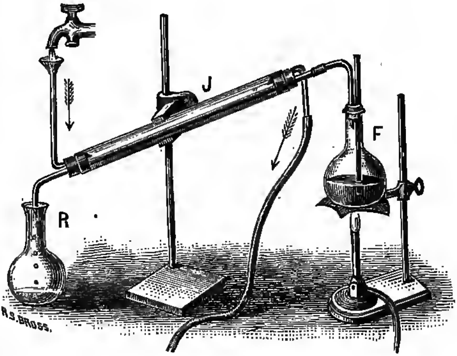


FIG. 301.

must be kept cool. This is done by constantly feeding it at the bottom with cold water, as explained in the last article.

(*a.*) Fig. 301 represents a simpler form of apparatus for this purpose. The retort is a Florence flask, the delivery tube of which passes through a "water-jacket." The method of supplying this condenser with cold water is evident from the figure. Sometimes the delivery tube passes directly into a vessel placed in a cold water bath, this vessel serving as both condenser and receiver.

578. Distillation of a Liquid from a Liquid.—Suppose that alcohol is to be separated from water. The solution is placed in the retort and heated to about 90° C., which is above the boiling point of alcohol but below that of water. The alcohol will pass over in a state of vapor and be condensed, while the water, etc., remains behind. In practice, the alcohol vapor passes over charged with a certain amount of steam. A receiver placed in a bath containing boiling water is interposed between the retort and the *worm* or condenser. In this receiver the steam condenses, while the vapor of alcohol passes on to the worm where it also is condensed. This process is known as "fractional distillation."

Recapitulation.—In this section we have considered the meaning of Liquefaction; the Laws of Fusion; the meaning and kinds of Vaporization; Evaporation in air and in vacuo; Ebullition and its Laws; effect of Pressure upon the boiling point; Steam; definition of Boiling Point; Distillation.

SECTION III.

LATENT AND SPECIFIC HEAT.

579. Thermal Units.—In § 538 it was stated that heat is measurable; but that we may measure it, a standard or unit of measure is necessary. *A thermal or heat unit is the amount of heat necessary to warm a weight unit of water one degree above the freezing point.* The weight unit generally used is the gram, kilogram or pound; any other weight unit may be used. The degree may be centigrade or Fahrenheit.

(*a.*) We have at least four units in use. They are the amounts of heat necessary to warm

(1.) A kilogram of water from 0° C. to 1° C. (A calorie.)
(2.) A gram of water from 0° C. to 1° C. (A lesser calorie.)
(3.) A pound of water from 0° C. to 1° C.
(4.) A pound of water from 32° F. to 33° F.

It makes no practical difference which unit is used, excepting so far as convenience is concerned, but the unit must not be changed during any problem.

580. Two Fruitful Questions.—We have already seen that heat melts ice, and that during the melting the temperature is constant; that heat boils water, and that during the boiling the temperature is constant. One feature of this change of condition remains to be noticed more fully. Take a block of ice with a temperature of −10° C. (14° F.) and warm it. A thermometer placed in it rises to 0° C. The ice begins to melt, but the mercury no longer rises. Heat is still applied, but there is no increase of temperature; the mercury in the thermometer remains stationary until the last particle of ice has been liquefied. Then, and not till then, does the temperature begin to rise. It continues to do so until the thermometer marks 100° C. The liquid then begins to boil, and the temperature a second time becomes fixed. But during all the time that the thermometer stood at 0° C., or while the ice was melting, heat was given by the lamp and received by the ice. Why then did not the temperature rise during that time, instead of remaining the same until the last particle of ice was melted? After the water began to boil, heat was continuously supplied. Why then was there not a continued increase of temperature?

581. Molecular Energies.—Heat is a form of energy and may be kinetic or potential. There can be no doubt that when a body is heated its molecules are thrown into violent motion, and that as the temperature is raised the energy of this molecular motion is increased, or that as this molecular motion is increased, the temperature is raised. But some of this molecular energy that we call heat, instead of being used to set the molecules of the body in motion, has work of a different kind to perform. That part of the heat which is spent in producing molecular vibrations, which increases the temperature, is called *sensible heat.* Another part is employed in pushing the molecules of the body asunder, producing expansion and change of condition. In forcing these molecules asunder, invisible energy of motion is changed to energy of position as truly and as necessarily as visible energy of motion is changed to the potential variety in throwing or carrying a stone from the earth to the house-top. (§ 159.)

582. Transmutation of Molecular Energy.—In most cases, but little of the heat communicated to a body is thus changed to potential energy, the greater part remaining energy of motion and increasing the temperature. But there are certain crises, or "critical occasions," on which the *greater* part of the heat communicated is transformed into energy of position. Thus, at the melting point, a large quantity of heat may be given to ice without affecting the temperature at all; instead of raising the temperature, it merely melts the ice. The energy used has been changed from the kinetic to the potential variety. In like manner, at the boiling point, a large quantity of heat may be given to the water without affecting the temperature at all. Instead of raising the temperature further, it merely vaporizes the water, and the steam has the same temperature as the water from which it came. The same change of molecular energy of motion into molecular energy of position has again taken place. This heat, which is thus used to overcome cohesion and change the condition of matter, does not affect the temperature and therefore is not *sensible*, but is stored up as potential energy and thus hidden or rendered *latent.*

583. Definition of Latent Heat.—*The latent heat of a substance is the quantity of heat that is* *lost to thermometric measurement during its liquefaction or vaporization, or the amount of heat that must be communicated to a body to change its condition without changing its temperature.* It may be made to reappear during the opposite changes after any interval of time. Many solids may undergo two changes of condition. Such solids have a latent heat of liquefaction and a latent heat of vaporization.

584. Latent Heat of Fusion.—We are already familiar with the fact that when ice or any other solid is melted by the direct application of heat, much of the heat is rendered latent. In the case of melting ice we shall show how this latent heat is measured, and that its quantity is very great. We may represent the process of liquefaction of ice as follows:

Water at 0° C. = ice at 0° C. + latent heat of water.

585. Latent Heat of Solution.—During the process of solution, as well as during fusion, heat is rendered latent. In either case the performance of the *work* of liquefaction demands an expenditure of kinetic energy. Hence *the solution of a solid involves a diminution of temperature.*

(*a.*) This loss may in some cases be made good by an equal increase, or changed to gain by a greater increase of sensible heat from the chemical changes involved; but in any case, the act of liquefaction considered by itself produces cold. Thus a cup of coffee is cooled by sweetening it with sugar, and a plate of soup is cooled by flavoring it with salt.

586. Freezing Mixtures.—*The latent heat of solution lies at the foundation of the action of freezing mixtures.* For example, when ice is melted by salt, and the water thus formed, in turn, dissolves the salt itself, the double liquefaction requires a deal of heat which is generally furnished by the cream in the freezer. The freezing mixture most commonly used consists of one weight of salt and two weights of snow or pounded ice. The mixture assumes a temperature of —18° C., which furnished the zero adopted by Fahrenheit.

(*a.*) By mixing, at the freezing temperature, three weights of snow with two weights of dilute sulphuric acid, the temperature may be reduced to about —20° F., a diminution of over 50 Fahrenheit degrees. If equal weights of snow and dilute sulphuric acid be thus reduced to a temperature of —20° F. and then mixed, the temperature will fall to about —60° F. By mixing equal weights of sodium sulphate crystals (Glauber's salt), ammonium nitrate and water, all at the ordinary temperature, and stirring the mixture with a thermometer, the temperature will be seen to fall from about 65° F. to about 10° F., which is considerably below the freezing point of pure water. Glauber's salt and chlorhydric (muriatic) acid form a good freezing mixture.

587. Solidification.—Solidification signifies the passage from the liquid to the solid condition. *During solidification there is an increase of temperature.* This may seem paradoxical in certain cases, but, even in the case of water, it is true that solidification is a warming process.

(*a.*) The sensible heat that disappeared as latent heat during liquefaction, being no longer employed in doing the work of maintaining liquidity, is reconverted into sensible heat and immediately employed in increasing the molecular vibrations. The molecular potential energy is transmuted into molecular kinetic energy. This is frequently illustrated by the precaution taken in winter to place tubs of water in vegetable cellars that the latent heat of the freezing water may be changed into sensible heat and thus protect the vegetables.

588. Temperature of Solidification.—The melting point is the highest temperature at which solidification can take place, but it is possible to keep substances in the liquid condition at lower temperatures. Water standing perfectly quiet sometimes cools several degrees below the melting point without freezing, but, upon agitation in any perceptible degree, solidification immediately takes place.

(*a*.) Persons who sleep in cold chambers sometimes notice, upon arising, that as soon as they touch a pitcher of water that has been standing in the room over night, the water quickly freezes. If a particle of ice be dropped into the water the same result follows. We may say that, in this condition, liquids have a tendency to freeze which is kept in check only by the difficulty of making a beginning.

589. Heat from Solidification.—(1.) By surrounding, with a freezing mixture, a small glass vessel containing water, and a mercury thermometer, the temperature of the water may be reduced to—10° C. or—12° C. without freezing the water. A slight movement of the thermometer in the water starts the freezing and the temperature quickly rises to 0° C.

(2.) Place a thermometer in a glass vessel containing water at 30° C. and a second thermometer in a large bath of mercury at —10° C. Immerse the glass vessel in the mercury. The temperature of the water will gradually fall to 0° C., when the water will begin to freeze and its temperature become constant. In the meantime the temperature of the mercury bath rises, and *continues to do so while the water is freezing.*

(3.) Dissolve two weights of Glauber's salt in one weight of hot water, cover the solution with a thin layer of oil and allow to cool, in perfect quiet, to the temperature of the room. By plunging a thermometer into the still liquid substance, solidification (crystallization) is started and the temperature rapidly rises. Dr. Arnott found that this experiment was successful after keeping the solution in the liquid condition for five years.

(4.) Mix equal quantities of dilute sulphuric acid and of a saturated solution of calcium chloride (not chloride of lime), the two liquids having been allowed time to acquire the temperature of the room. The two liquids are converted into solid calcium sulphate, with a marked increase of temperature. In this case, as in some of the other cases, part of the heat observed is probably due to chemical action, but more to the conversion of the latent heat of the liquids.

(5) To three weights of quicklime add one weight of water. The water will be completely solidified in the slaking of the lime with remarkable thermal manifestations. Carts containing quicklime have been set on fire by exposure to heavy rains.

590. Change of Bulk during Solidification.

—Most substances shrink in size during solidification; but a few, such as ice, cast-iron, antimony and bismuth, are exceptions. When melted cast-iron is poured into a mould, it expands in solidifying and presses into every part of the mould. The tracings on the casting are, therefore, as clear cut as they were in the mould. A clear-cut casting can not be obtained from lead; this is one of the reasons why antimony is made a constituent of type-metal. Gold coins have to be stamped; they cannot be cast so as to produce a clear-cut design. The bursting of pipes by freezing water is a common source of annoyance.

(*a*.) An army officer at Quebec performed the following experiment: He filled a 12-inch shell with water and closed the opening with a wooden plug forcibly driven in. The shell was put out of doors; the temperature being −28° C., the water froze, the plug was thrown about 300 feet, and a tongue of ice about eight inches long protruded from the opening. In a similar experiment, the shell split and a rim of ice issued from the rent.

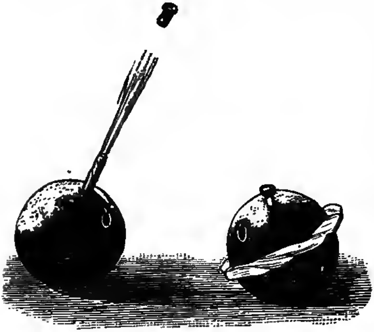


FIG. 302.

591. Latent Heat of Vaporization.—The vaporization of a liquid is accompanied by the disappearance of a large quantity of heat, and frequently by a diminution of temperature. There is a change of sensible into latent heat; of kinetic into potential energy. We may represent, for instance, the vaporization of water as follows:

Steam at 100° C. = water at 100° C. + latent heat of steam.

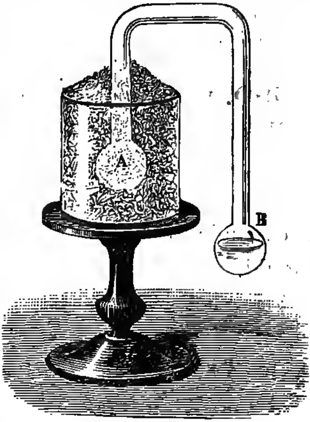


FIG. 303.

(*a.*) The cryophorus, shown in Fig. 254, consists of a bent tube and two bulbs containing a small quantity of water. The air is removed by briskly boiling the water. The tube is sealed while the steam is escaping. The instrument thus contains only water and aqueous vapor. When the liquid is poured into *B*, and *A* is placed in a freezing mixture, the vapor is largely condensed in *A* while more is rapidly formed in *B*. Crystals of ice soon form on the surface of the water in *B*.

(*b.*) Wet a block of wood and place a watch crystal upon it. A film of water may be seen under the central part of the glass. Half fill the crystal with sulphuric ether and rapidly evaporate it by blowing over its surface a stream of air from a small bellows. So much heat is rendered latent in the vaporization that the watch crystal is firmly frozen to the wooden block.

(*c.*) Sulphurous oxide (SO_2) previously dried, is easily liquefied by passing it through a U-tube immersed in a freezing mixture. When some of this liquid is placed upon mercury in a small capsule and rapidly evaporated by blowing over it a stream of air from a bellows, *the mercury is frozen* (§ 562). (See Chemistry, Exp. 146.)

592. Condensation of Gases.—Gases may be condensed by union with some liquid or solid, by cold or by pressure. It has been recently shown that any known gas may be liquefied by cold and pressure. In any case, *the condensation of a gas renders sensible a large amount of heat.*

(*a.*) The change of latent heat into sensible during the condensation of a gas is easily illustrated by the following experiment: Into a gas bottle, *A*, put a teacup full of small pieces of marble, and pour in enough water to cover them and to seal the lower end of the thistle tube. From the gas bottle lead a delivery tube to the lower part of a bottle, *B*, containing a thermometer, *t*. From this bottle lead a tube to the lower part of the bottle *C*, which contains a thermometer, *T*, with its lower part embedded in a teacup full of salts of tartar. Through the thistle tube of *A* pour muriatic acid, about a thimble-full at a time. Carbonic acid gas will be liberated and pass through *B* into *C*. There it unites with the potassium carbonate, changing it to potassium bi-carbonate. In this change from the aëriform to the solid condition, the carbonic acid gives up all its latent heat, as is shown by the remarkable rise of the thermometer in *C*. That this increase of temperatnre is not due to the sensible heat of a hot gas is shown by the fact that *t* is scarcely affected during the experiment.

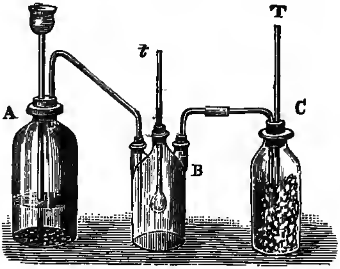


FIG. 304.

(*b.*) When the vapor is condensed to the liquid or solid form, the heat previously rendered latent is given ont as sensible heat; that is, the energy of position is changed back to energy of motion. In coming together again, the particles yield the same amount of kinetic energy as was consumed in their separation.

593. The Heat Equivalent of the Fusion of Ice.—If one pound of water at 0° C. be mixed with one pound of water at 80° C., we shall have two pounds of water at 40° C. But if one pound of ice at 0° C. be mixed with one pound of water at 80° C., we shall have two pounds of water at 0° C The heat which might be used to warm the water from 0° to 80° C., has been used in melting a like weight of ice. Hence, by our definition, we see that the latent heat of one kilogram of water is 80 calories. This means that *the amount of heat required to melt a quantity* *of ice without changing its temperature is eighty times as great as the heat required to warm the same quantity of water one centigrade degree.*

(*a.*) Because of this great latent heat of water, the processes of melting ice and freezing water are necessarily slow. Otherwise, the waters of our northern lakes might freeze to the bottom in a single night, while "the hut of the Esquimaux would vanish like a house in a pantomime," or all the snows of winter be melted in a single day with inundation and destruction.

594. The Heat Equivalent of the Vaporization of Water.—Experiment has shown that the amount of heat necessary to evaporate one weight unit of water would suffice to raise the temperature of 537 weight units of water 1° C. Hence, we say that the latent heat of one kilogram of steam is 537 calories. This means that *the amount of heat required to evaporate a quantity of water without changing its temperature is 537 times as great as the heat required to warm the same quantity of water one centigrade degree.*

(*a.*) When a pound of steam is condensed, 537 heat units (pound-centigrade) are liberated. In this, we see an explanation of the familiar fact that scalding by steam is so painfully severe. Were it not for the latent heat of steam, when water reached its boiling point it would instantly flash into steam with tremendous explosion.

595. Problems and Solutions.—(1.) How many grams of ice at 0° C. can be melted by 1 gram of steam at 100° C.? One gram of steam at 100° C., in condensing to water at the same temperature, parts with all its latent heat, or 537 lesser calories. The gram of water thus formed can give out 100 more heat units. Hence, the whole number of lesser calories given out by the steam in changing to water at 0° C., the temperature at which it can no longer melt ice, is $537 + 100 = 637$.

Let $x =$ the number of grams of ice that can be melted. Each gram of ice melted will require 80 lesser calories. Hence, $80x =$ the number of heat units necessary. The heat to melt the ice must come from the steam.

Therefore, $80x = 637$. $\therefore\ x = 7.96 +$ grams. *Ans.*

(2.) How many pounds of steam at 100° C. will just melt 100 pounds of ice at 0° C.? If x represent the number of pounds of steam required, that quantity of steam at 100° C. will furnish $637x$ heat units. To melt 100 lbs. of ice, (80 × 100 =) 8,000 heat units will be required.

Hence, $637x = 8{,}000$. $\therefore\ x = 12.55 +$ lbs. *Ans.*

(3.) What weight of steam at 100° C. would be required to raise 500 pounds of water from 0° C. to 10° C.?

Let $x =$ the number of pounds of steam required.

$(537 + 90)x = 500 \times 10$. $\therefore\ x = 7.97 +$ lbs. *Ans.*

(4.) If 4 lbs. of steam at 100 C. be mixed with 200 lbs. of water at 10° C., what will be the temperature of the water?

Let $x =$ the temperature. In condensing to water at 100° C., the 4 lbs. of steam will give out (537 × 4 =) 2,148 heat units. This 4 lbs. of water will then give out $4(100 - x)$ heat units. Hence, the steam will impart $2{,}148 + 4(100 - x)$ heat units. The 200 lbs. of water in rising from 10° C. to $x°$ will absorb $200(x - 10)$ heat units.

Hence, $2{,}148 + 4(100 - x) = 200(x - 10)$. $\therefore\ x = 22.29°$ C. *Ans.*

596. Illustration of Specific Heat. — When the temperature of a body changes from 30° to 20°, the body loses just as much heat as it gained in passing from 20° to 30°. This heat lost by a cooling body may be measured, like any other energy, by the work it can perform. If equal weights of different bodies be raised to the same temperature, the amount of ice that each can melt will be proportional to the number of thermal units they severally contain. A pound of sulphur at 212° F. will melt $\frac{1}{5}$ as much ice as a pound of boiling water. Hence, it required only $\frac{1}{5}$ as much heat to heat the sulphur from the freezing point to 212° F., as it did to heat the water to the same temperature; in scientific phraseology, the specific heat of sulphur is $\frac{1}{5}$.

(*a.*) In an experiment of this kind, if the cooling substance change its condition, the latent heat set free as sensible heat must be taken into account. Special precaution must also be taken in measuring the heat expended, to avoid melting of the ice by the heat of the surrounding air and making proper allowance for the heat expended in warming the apparatus itself. Fig. 256 represents a form of *calorimeter* frequently used in such experiments. *M* contains the heated body whose weight and temperature are known. *A* contains the ice to be melted, the liquid thus produced escaping by *D*. *B* is an ice jacket to prevent melting of the ice in *A* by the heat of the air.

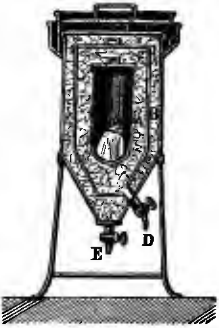


FIG. 305.

597. Definition of Specific Heat.

—*The specific heat of a body is the ratio between the quantity of heat required to warm that body one degree and the quantity of heat required to warm an equal weight of water one degree.*

(*a*.) It is very important to bear in mind that specific heat, like specific gravity, is a ratio ; nothing more nor less. The specific heat of water, the standard, is unity. This ratio will be the same for any given substance, whatever the thermal unit or thermometric scale adopted.

598. Specific Heat Determined by Mixture.

—One of the simplest methods of measuring specific heat is by mixture. Suppose, *e. g.*, that 3 kilograms of mercury at 100° C. are mixed with 1 kilogram of ice-cold water and that the temperature of the mixture is 9° C. How shall we find the specific heat of mercury?

Let $x =$ the specific heat of the mercury, or the amount of heat lost by one kilogram of mercury for each degree of change of temperature. Then will

$3x =$ the number of heat units lost by the given amount of mercury for every degree of change of temperature, and 91 times $3x$, or

$273x =$ the number of heat units lost by the mercury in passing from 100° to 9° C.

The specific heat of water is 1. This multiplied by the number of kilograms of water taken is 1, which represents the number of heat units gained by that quantity of water for each degree of change of temperature. Then will 9 represent the number of heat units gained by the water in passing from 0° to 9°. But no heat has been destroyed or wasted; what the mercury has lost, the water has gained.

	Mercury.		*Water.*
Specific heat	x		1
Weights taken	3		1
No. of degrees of change	91		9
Heat units	$273x$	=	9

$\therefore\ x = .033$, the specific heat of mercury.

599. Heated Balls Melting Wax.—The difference between bodies in respect to specific heat may be roughly illustrated as follows: small balls of equal weight, made severally of iron, copper, tin, lead and bismuth are heated to a temperature of 180° or 200° C. by immersing them in hot oil until they all acquire the temperature of the oil. They are then placed on a cake of beeswax about half an inch thick. The iron and copper will melt their way through the wax, the tin will nearly do so, while the lead and bismuth sink not more than half way through the wax.

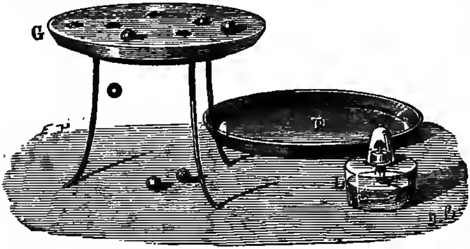


FIG. 306.

600. Reference Tables.—(1.) Specific Heat of some substances:

Hydrogen	3.4090	Iron	.1138
Water	1.0000	Copper	.0952
Ammonia (gas)	.5084	Silver	.0570
Air	.2375	Tin	.0562
Oxygen	.2175	Mercury	.0333
Sulphur	.2026	Lead	.0314
Diamond	.1469	Bismuth	.0308

(2.) Specific heat of some substances in different states:

	Solid.	*Liquid.*	*Aeriform*
Water	.5050	1.0000	.4805
Bromine	.0843	.1060	.0555
Alcohol	.....	.5050	.4534
Ether	.....	.5467	.4797

601. Specific Heat of Water.—*Water in its liquid form has a higher specific heat than any other substance except hydrogen.* For this reason the ocean and our lakes are cooled and heated more slowly than the land and atmosphere. They thus modify sudden changes of temperature, and give rise to the well known fact that the climate of the sea-coast is warmer in winter and cooler in summer than that of inland places of the same latitude. The heat of summer is stored up in the ocean and slowly given out during the winter. This fact also explains a phenomenon familiar to those living on the borders of the ocean or great lakes. Because of its lower specific heat, the land becomes during the day more heated than the water. The air in contact with the land thus becomes more heated, expands, rises and forms an *upper* current from the land accompanied by a corresponding *under* current to the land, the latter constituting the welcome sea or lake breezes of summer. After sunset, however, the land cools more rapidly than the water, the process is reversed, and we have an under current from the land constituting the land breeze.

EXERCISES.

1. One kilogram of water at 40° C., 2 kilograms at 30° C., 3 kilograms at 20° C., and 4 kilograms at 10° C. are mixed. Find the temperature of the mixture.

2. One pound of mercury at 20° C. was mixed with one pound of

water at 0° C., and the temperature of the mixture was 0.634° C. Calculate the specific heat of mercury.

3. What weight of water at 85° C. will just melt 15 pounds of ice at 0° C.? *Ans.* 14.117 lb.

4. What weight of water at 95° C. will just melt 10 pounds of ice at −10° C.? *Ans.* 8.94 lb.

5. What weight of steam at 125° C. will melt 5 pounds of ice at −8° C. and warm the water to 25° C.? *Ans.* 0.87 lb.

6. How much mercury could be warmed from 10° C. to 20° C. by 1 kilogram of steam at 200° C.? *Ans.* 2172.72 *Kg.*

7. Equal masses of ice at 0° C. and hot water are mixed. The ice is melted and the temperature of the mixture is 0° C. What was the temperature of the water? *Ans.* 80° C.

8. Ice at 0° C. is mixed with ten times its weight of water at 20° C. Find the temperature of the mixture. *Ans.* 11° C. nearly.

9. One pound of ice at 0° C. is placed in 5 pounds of water at 12° C. What will be the result?

10. Find the temperature obtained by condensing 10 *g.* of steam at 100° C. in 1 *Kg.* of water at 0° C. *Ans.* 6.3° C.

11. A gram of steam at 100° C. is condensed in 10 grams of water at 0° C. Find the resulting temperature. *Ans.* 58° C. nearly.

12. If 200 *g.* of iron at 300° C. be plunged into 1 *Kg.* of water at 0° C., what will be the resulting temperature? *Ans.* 6.67° C.

13. Find the specific heat of a substance, 80 *g.* of which at 100° C., being immersed in 200 *g.* of water at 10° gives a temperature of 20° C.

14. If 300 *g.* of copper at 100° C. be immersed in 700 *g.* of alcohol at 0° C., what will be the resulting temperature? (§ 600.)

15. What will be the result of mixing 5 ounces of snow at 0° C. with 23 ounces of water at 20° C.?

16. A pound of wet snow mixed with 5 pounds of water at 20° C. yields 6 pounds of water at 10° C. Find the proportions of snow and water in the wet snow.

17. What weight of mercury at 0° C. will be raised one degree by dropping into it 150 *g.* of lead at 400° C.?

18. Find the result of mixing 6 pounds of snow at 0° C. with 7 pounds of water at 50° C.

Recapitulation.—In this section we have considered the definition of Thermal Units; two Varieties of Molecular Energy; their mutual Convertibility; the definition of Latent Heat; the latent heat of Fusion and of Solution; Freezing Mixtures; Solidification, and the Temperature of Solidification; Heat from Solidification; Change of Bulk during solidifying; the Latent Heat of Vaporization; the Condensation of Gases; the Latent Heat of Water and of Steam; illustration and definition of Specific Heat; specific heat Determined by Mixture; specific heat Determined by Melting Wax; tables of specific heat, and the Specific Heat of Water.

SECTION IV.

MODES OF DIFFUSING HEAT.

602. Diffusion of Heat.—Heat is diffused in three ways: by conduction, convection, and radiation. Whatever the mode of diffusion, there is a tendency to produce uniformity of temperature.

603. Conduction.—If one end of an iron poker be thrust into the fire, the other end will soon become too warm to be handled. It has been heated by conduction, the molecules first heated giving some of their heat to those adjacent, and these passing it on to those beyond. There was a transfer of motion from molecule to molecule. *The process by which heat thus passes from the hotter to the colder parts of a body is called conduction of heat.* The propagation is very gradual, and as rapid through a crooked as through a straight bar.

604. Differences in Conductivity.—If, instead of an iron poker, we use a glass rod or wooden stick, the end of the rod may be melted or the end of the stick

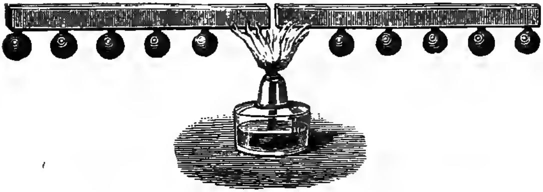


FIG. 307.

burned without rendering the other end uncomfortably warm. We thus see that some substances are good conductors of heat while some are not. Thrust a silver and a German silver spoon into the same vessel of hot water, and the handle of the former will become much hotter than that of the latter.

(*a.*) Fig. 307 represents a bar of iron and one of copper placed end to end so as to be heated equally by the flame of the lamp. Small balls (or nails) are fastened by wax to the under surfaces of the bars at equal distances apart. More balls can be melted from the copper than from the iron. The *number* of balls melted off, not the *rapidity* with which they fall, is the test of conductivity. The rapidity would depend more upon specific heat.

(*b.*) Relative thermal conductivity of some metals:

Silver	100	Iron	12
Copper	74	Lead	9
Gold	53	Platinum	8
Brass	24	German silver	6
Tin	15	Bismuth	2

The above-named metals arrange themselves in the same order with reference to the conduction of electricity, silver being the best and bismuth the poorest. This relation suggests a similarity of nature between these two agents.

605. Conductivity of Fluids.—*Liquids and aeriform bodies are poor conductors of heat.* The surface of a liquid may be intensely heated without sensibly affecting the temperature an inch below.

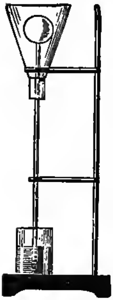


FIG. 308.

(*a.*) Cork the neck of a glass funnel and pass the tube of an inverted thermometer through the cork, or use an air thermometer, as shown in the figure. Cover the thermometer bulb to the depth of about half an inch with water. Upon the water pour a little sulphuric ether and ignite it. The heat of the flame will be intense enough to boil a small quantity of water held *over* it, but the thermometer below will be scarcely affected. Fasten a piece of ice at the bottom of a glass tube, and cover it to the depth of several inches with water. Hold the tube at an angle of about 45°, and apply the flame of a lamp below the upper part of the water. The water there may be made to boil without melting the ice. The conductivity of gases is probably lower than that of liquids.

606. Convection.—Fluids (with the exception of mercury, which is a metal) being poor conductors, they cannot be heated as solids generally are. Water, *e.g.*, must be heated *from below*; the heated molecules expand and rise while the cooler ones descend to take their place at the source of heat. These currents in heating water may be made visible by dropping a small quantity of cochineal or oak sawdust into the vessel containing the water. *This method of diffusing heat, by actual motion of heated fluid masses, is called convection.* Expansion by heat and the force of gravity are essential to convection. Since aëriform bodies are expanded more by heat than liquids are, these currents of heated gases are more active than those of liquids. Hence the drafts of lamps and stoves, the existence of trade winds, etc.

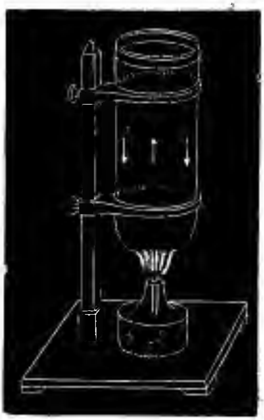


FIG. 309.

607. The Third Mode of Heat Diffusion.—When a hand is held over a heated stove, heat is carried to the hand by convection and given up to the hand by conduction. But when the hand is held before the stove it is also heated, not by conduction, for fluids have little conducting power; not by convection, for convection currents are ascending. How then does the heat get to the hand? The query comes to us with still greater force when we consider the transmission of the sun's heat to the earth, for the atmosphere can carry it by neither conduction nor convection. More important yet, how does the sun's heat reach the earth's atmosphere? This heat passes through the atmosphere without heating it. If along a poker thrust into the fire the hand be moved toward the stove, the temperature increases. If a person ascend through the atmosphere toward the sun the temperature diminishes. We have here a wholly new set of thermal phenomena, heat passing through a substance and leaving the condition of that substance unchanged.

608. Luminiferous Ether.—In the case of actual, mechanical energy, the rapid motion of bodies, *e. g.*, a vibrating guitar string, is partly carried off by the air in the shape of sound. When the sound reaches the auditory nerve it represents a certain amount of mechanical energy of motion which has been carried from the string by the air. *There is sufficient reason for believing that there is a medium pervading all space which carries off part of the invisible motions of molecules, just as the air carries off a portion of the motion of moving masses.* This medium, called the luminiferous ether, occupies all space. The gaps between the sun, the planets and their satellites are filled with this ether. "It makes the universe a whole and renders possible the intercommunication of light and energy between star and star."

609. Density and Elasticity of the Ether.—This ether is wonderful, not only in its incomprehensible vastness but equally so in its subtleness. While it surrounds the suns of unnumbered systems and fills all interstellar space, it also surrounds the smallest particles of matter and fills intermolecular space as well. It is called luminiferous because it is the medium by which light is propagated, it serving as a common carrier for both heat and light. We have seen (§ 426) that the velocity of sound depends upon two considerations, the elasticity and the density of the medium. The enormous velocity with which the ether transmits heat and light as wave motion (about 186,000 miles *per* second), compels us to assume for the ether both extreme elasticity and extreme tenuity.

610. Radiant Heat.—We have seen that the molecules of a heated body are in a state of active vibration. The motion of these vibrating molecules is communicated to the ether and transmitted by it, as waves, with wonderful velocity. Thus, when you hold your hand before a fire, the warmth that you feel is due to the impact of these ether-waves upon your skin; they throw the nerves into motion, just as sound-waves excite the auditory nerve, and the consciousness corresponding to this motion is what we popularly call warmth. *Heat thus propagated by the ether, instead of by ordinary forms of matter, is Radiant Heat. The process of propagation is called radiation.*

611. The Transmission through a Vacuum.—*Radiant heat will traverse a vacuum.* We might infer this from the fact that the sun radiates heat to the earth. It may be also shown experimentally.

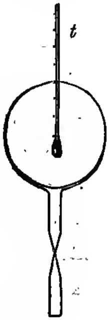


FIG. 310.

(*a*.) A thermometer is sealed air-tight in the bottom of a glass globe in such a way that the bulb is near the centre of the globe. The neck of the flask is to be about a yard long. The apparatus being filled with mercury and inverted over a mercury bath, a Torricellian vacuum is formed in the globe and upper part of the tube. The tube is then melted off above the mercury. When the globe is immersed in hot water, the thermometer immediately indicates a rise of temperature. There is no chance for convection; conduction acts much more slowly.

612. Rectilinear Propagation.—*Radiant heat travels in straight lines through any uniform medium.*

(*a.*) Between any source of heat and a thermometer place several screens. If holes be made in the screens (See Fig. 321) so that a straight line from the source of heat to the thermometer may pass through them, the thermometer will be affected by the heat. By moving one of the screens so that its opening is at one side of this line, the heat is excluded. In a very warm day a person may step from a sunny into a shady place for the same reason. The heat that moves along a single line is called a ray of heat.

613. Radiation Equal in all Directions.—*Heat is radiated equally in all directions.* If an iron sphere or a kettle of water be heated, and delicate thermometers placed on different sides of it at equal distances, they will all indicate the same temperature.

614. Radiation Depends upon Temperature of the Source.—*The intensity of radiant heat is proportional to the temperature of the source.*

(*a.*) Near a differential thermometer, place a vessel of water 10° warmer than the temperature of the room. Notice the effect upon the thermometer. Heat the water 10° more and repeat the experiment at the same distance. Then heat the water 10° still more and repeat the experiment again. The effects upon the thermometer will be as the numbers one, two and three.

615. Effect of Distance.—*The intensity of radiant heat varies inversely as the square of the distance.*

(*a.*) Place the differential thermometer at a certain distance from the heated water and note the effect. Removing the thermometer to twice that distance the effect is only one-fourth as great, etc.

616. Incident Rays.—When radiant heat falls upon a surface it may be transmitted, absorbed or reflected. If transmitted, it may be refracted. Rock salt crystal transmits nearly all, reflects very little, and absorbs hardly any. Lampblack absorbs nearly all, reflects very little, and transmits none. Polished silver reflects nearly all, absorbs a little, and transmits none.

617. Diathermancy.—*Bodies that transmit radiant heat freely are called diathermanous; those that do not are called athermanous.* These terms are to heat, what transparent and opaque are to light. Rock salt is the most diathermanous substance known. Heat that is radiated from a non-luminous source, as from a ball heated below redness, is called *obscure* heat; while part of that radiated from a luminous source, as from the sun or from a ball heated to redness, is called *luminous* heat. Heat from a luminous source is generally composed of both luminous and obscure rays.

618. Selective Absorption.—The power of any given substance to transmit heat varies with the nature of the heat or of its source. For example, glass, water or alum allows the sun's luminous heat rays to pass, while absorbing nearly all of the heat rays from a vessel filled with boiling water. In other words, these substances are diathermanous for luminous rays, but athermanous for obscure rays. The physical difference between luminous and obscure heat rays will subsequently be explained.

(*a.*) A solution of iodine in carbon di-sulphide transmits obscure rays but absorbs luminous rays. By means of these substances, luminous and obscure rays may be sifted or separated from each other. Dry air is highly diathermanous; watery vapor is highly athermanous for obscure rays.

619. Reflection of Heat.—When radiant heat falls upon an athermanous body, part of it is generally absorbed and raises the temperature of the body. The rest is reflected, the energy still existing in the ether waves. *The angle of incidence equals the angle of reflection* (§ 97).

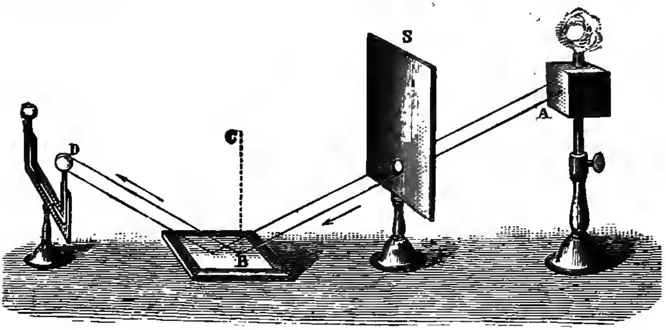


FIG. 311.

(*a*.) In Fig. 311, the source of heat at *A* is a Leslie's cube filled with hot water. *S* is an athermanous screen with an aperture for the passage of rays from *A* to the reflector *B*. The line *CB* is perpendicular to the reflector. When *D*, the bulb of the differential thermometer, is placed so that the angle *ABC* equals the angle *DBC*, the reflected rays will strike the bulb and raise the temperature.

620. Reflection by Concave Mirrors.—By the use of spherical or parabolic mirrors, remarkable heating effects may be produced. When parallel rays (like the sun's rays) strike directly upon such a mirror, they are reflected to a focus. Any easily combustible substance held at the focus may be thus ignited.

(*a*.) Two such mirrors may be placed as shown in Fig. 312. At the focus of one reflector place a hot iron ball; at the focus of the other, a bit of phosphorus or gun-cotton. If the apparatus be arranged with exactness, the combustible will be quickly ignited.

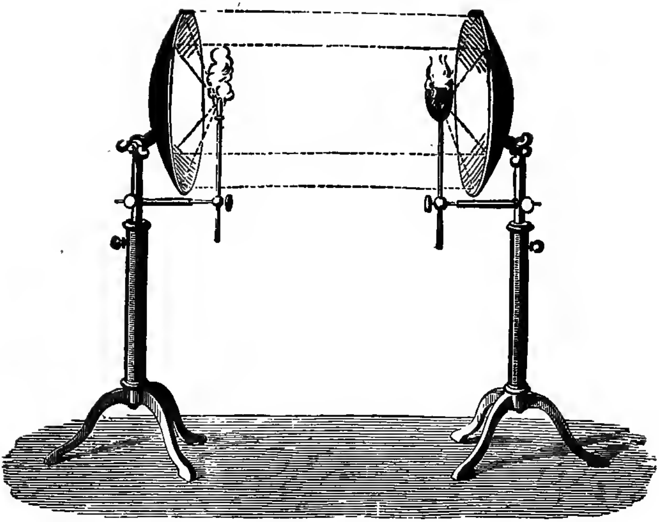


FIG. 312.

Replace the iron ball with a Leslie's cube containing hot water; at the focus of the other reflector place one bulb of the differential thermometer. The rise of temperature at this focus will be clearly shown, *even when the other bulb is nearer the source of heat than the focus is.*

621. Refraction of Heat.—When rays of heat fall obliquely upon a diathermanous body, they will be bent from a straight line on entering and leaving the body. *This bending of the ray is called refraction.* Many rays of heat may thus be concentrated at a focus, as in the case of a common burning-glass. By the aid of a spectacle-glass, the sun's rays may be made to ignite easily combustible substances. The refraction of obscure rays cannot be shown by a glass lens, since glass is athermanous for such rays. But if a rock-salt lens be held before a source of obscure heat, and the face of a thermopile placed at the focus of the lens, the galvanometer needle will at once turn aside, showing a rise of temperature. If the face of the pile be placed anywhere else than at the focus, there will be no such deflection of the needle.

622. Change of Radiant into Sensible Heat.—Of all the rays falling upon any substance, only those that are absorbed are of effect in heating the body upon which they fall. The motion of the ether waves may be changed into vibrations of molecules of ordinary matter, and thus produce sensible heat, but the same energy cannot exist in waves of ether and in ordinary molecular vibrations at the same time.

(*a.*) Phosphorus or gun-cotton may be ignited by solar rays at the focus of a lens made of clear *ice*. The heat rays pass through the ice without melting it. It is only when the radiation is stopped that the energy of the ray can warm anything.

623. Determination of Absorbing, Reflecting and Radiating Powers.—For experiments in determining the absorbing, reflecting and radiating powers of solids, the apparatus generally used consists of a Leslie's cube, concave mirrors of different materials, and a differential thermometer or a thermopile. The Leslie's cube is a box about three inches on each edge, the sides being made of, or covered with, different materials, to show their differences in radiating power. The cube filled with hot water is placed before the reflector, and a bulb of the thermometer is placed at the focus. By turning different faces of the cube toward the mirror, the relative radiating powers are determined. By using different mirrors, the reflecting powers are determined. By coating the bulb with different substances, their absorbing powers are determined. The relative radiating powers of several common substances are as given below:

Lampblack	100	Tarnished lead	45
Paper	98	Mercury	20
Crown glass	90	Gold, silver, copper	12

624. Mutual Relations of Absorption, Reflection and Radiation.—By means like those men tioned in the last paragraph, it has been shown that *good absorbents are good radiators and poor reflectors, and vice versa;* that the radiating power of a body depends largely upon the nature of its surface; that smoothing and polishing the surface increases reflecting power, and diminishes absorbing and radiating power; that roughening and tarnishing the surface increases the absorbing and radiating powers, and diminishes the reflecting power. *The powers of absorption and radiation go hand in hand.*

(*a.*) Make a thick paint of a teaspoonful of lampblack and a little kerosene oil. With this, paint the right-hand face of the left-hand bulb (tin can of the differential thermometer described in Appendix R). Provide another oyster can and paint one side with the lampblack. Fill this third can with boiling water and place it on the wooden strips, *midway* between the two tin bulbs, the two blackened surfaces facing each other. The heat radiated and absorbed by the two blackened surfaces will exceed the heat radiated and absorbed by the two equal unpainted surfaces that face each other. The movement of the colored alcohol in the tube will show this to be true.

625. Sympathetic Vibrations.—The relation between radiation and absorption of heat is closely analogous to the relation between the radiation and absorption of sound. If a set of sound waves fall upon a string capable of producing similar waves, the string is set in motion and the sound waves weakened (§ 509). When ether waves of a given kind fall upon a body whose molecules are able to vibrate at the same rate, and thus to reproduce similar waves, the kinetic energy is transferred from the ether to the molecules, the molecules are heated, the radiant energy *absorbed.* This ability to absorb wave motion of any particular kind, implies the ability to reproduce the same kind of waves. It therefore is easily seen that *a body that can absorb any particular kind of heat rays can radiate the same kind.*

Note.—It will be seen further on, that obscure heat rays differ from light *only in the matter of wave length.* Most of the phenomena of one may be shown to pertain to the other. Absorption, radiation, reflection, transmission and refraction of rays follow the same laws, whether the agent be called heat or light. Other phenomena, such as interference and polarization, more satisfactorily studied with luminous rays, have been produced with obscure rays. It should be borne in mind that the most delicate instruments yet made are far less sensitive to obscure heat than is the eye to light. A candle flame may be seen a mile away; any one might well be pleased with an instrument that would detect its heat at the distance of a rod.

QUESTIONS.

1. Good conductors feel warmer or cooler to the touch than poor conductors of the same temperature. Why?
2. Why is it so oppressively warm when the sun shines *after* a summer shower?
3. Why is there greater probability of frost on a clear than on a cloudy night?
4. Can a good absorbent be a good reflector of heat? Is a good absorbent a good radiator, or otherwise?
5. Explain why the glass covering of a hot-bed or conservatory renders the confined air warmer than the atmosphere outside.
6. From your own experience, decide which is the better conductor of heat, linen or woolen goods, oil-cloth or carpet.
7. Why are the double walls of ice-houses filled with sawdust? Why do fire-proof safes have double walls inclosing plaster-of-Paris or alum?
8. Why do furnace men, firemen and harvesters wear woolen clothing? Explain the use of double windows.
9. How may heat be diffused? How is the surface of the earth and how is the atmosphere heated? Can you boil water in a vessel with heat applied from above? Why?

Recapitulation.—In this section we have considered Conduction; the conductivity of Fluids; Convection; the Luminiferous Ether, its Density and Elasticity; Radiant Heat, and Radiation; Diathermancy; Selective Absorption; Reflection from plane and concave surfaces; Refraction; the Change from radiant into sensible heat; the determination of Absorbing, Reflecting and Radiating Powers, and their Mutual Relations; Sympathetic Vibrations.

SECTION V.

THERMODYNAMICS.

626. Definition of Thermodynamics.—*Thermodynamics is the branch of science that considers the connection between heat and mechanical work.* It has especial reference to the numerical relation between the quantity of heat used and the quantity of work done.

627. Correlation of Heat and Mechanical Energy.—We know that heat is not a form of matter because *it can be created in any desired quantity.* We must continually remember that it is a form of energy. When heat is produced some other kind of energy must be destroyed. Conversely, when heat is destroyed, some other form of energy is created. Considered as heat merely, this agent may be annihilated; considered as energy, it may only be transformed. The most important transformations of energy are those between heat and mechanical energy. The process of working these transformations will be considered directly. It is to be noticed, however, that while we may be able to effect a *total* conversion of mechanical energy into heat, we are not able to bring about a total conversion of heat into mechanical energy.

628. Heat from Percussion.—A small iron rod placed upon an anvil may be heated to redness by repeated blows of a hammer. The energy of the moving mass is broken up, so to speak, and distributed among the molecules, producing that form of molecular motion that we call heat. The same transformation was illustrated in the kindling of a fire by the "flint and steel" of a century ago. It may be experimentally illustrated by the "air-syringe."

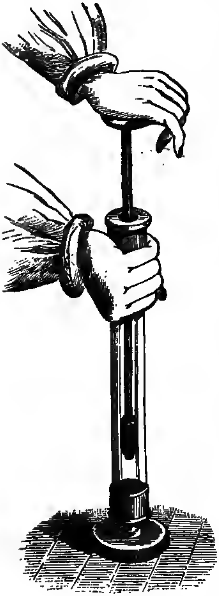


FIG. 313.

(*a*.) The air-syringe consists of a cylinder of metal or glass and an accurately fitting piston. By suddenly driving in the piston, the air is compressed and heat developed. A bit of gun cotton previously placed in the cylinder may thus be ignited. If the cylinder be made of glass, and a bit of ordinary cotton dipped in sulphuric ether be used, repeated flashes of light may be produced by successive combustions of ether vapor. The fumes of one combustion must be blown away before the next combustion is attempted.

629. Heat from Friction.—Common matches are ignited and cold hands warmed by the heat developed by friction. It is said that some savages kindle fires by skilfully rubbing together well-chosen pieces of wood. In the case of the axles of railway cars and ordinary carriages, this conversion of mechanical energy into heat is not so difficult as its prevention. Lubricants are used to diminish the friction and prevent the waste of energy due to the undesirable transformation. A railway train is really stopped by the conversion of its motion into heat. When this has to be done quickly, the change is hastened by increasing the friction by means of the brakes. Examples of this change are matters of every day experience.

(*a*.) Attach a brass tube 10 *cm*. long, about 2 *cm*. in diameter and closed at the bottom, to a whirling table. Partly fill the tube with alcohol and cork the open end. Press the tube between two pieces of board hinged together as shown in the figure. The boards should have two grooves for the reception of the tube; the inner faces of the boards may be covered with leather. When the machine is set in motion, the friction warms and soon *boils the alcohol*. The vapor drives out the cork with explosive violence.

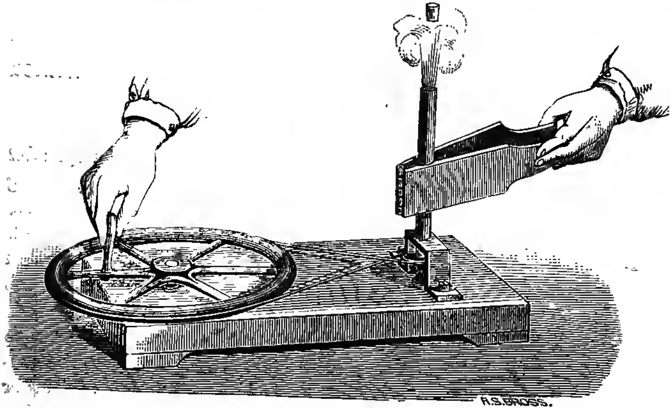


FIG. 314.

630. First Law of Thermodynamics.—*When heat is transformed into mechanical energy or mechanical energy into heat, the quantity of heat equals the quantity of mechanical energy.* This principle is the corner-stone of thermodynamics. It is a particular case under the more general law of the Conservation of Energy.

631. Joule's Equivalent.—It is a matter of great importance to determine the numerical relation between heat and mechanical energy; to find the equivalent of a heat unit in units of work. This equivalent was first ascertained by Dr. Joule, of Manchester, England. His experiments were equal in number and variety to the importance of the subject. He showed that the mechanical value of the heat required to warm a given weight of water—

1° C., would lift the water..........	424 meters against gravity. 1,390 feet " "
1° F., would lift the water............	772 " " "

and represents 41,595,000,000 ergs per calorie.

Any weight unit may be used without changing the above values which should be remembered.

Referring to centigrade degrees, we say that the mechanical value of a calorie is 424 kilogrammeters or that of the third unit (§ 579 *a*) is 1,390 foot-pounds.

Referring to the fourth heat unit mentioned in § 579 (*a*), we say that its mechanical value is 772 foot-pounds.

632. The Use of Joule's Equivalent.—The use of the mechanical equivalent of heat may be well shown by the solution of a problem.

(*a*.) If a cannon-ball weighing 192.96 pounds and moving with a velocity of 2000 feet per second, be suddenly stopped and all of its kinetic energy converted into heat, to what temperature would it warm 100 pounds of ice-cold water?

Kinetic energy $= \frac{wv^2}{2g} = \frac{192.96 \times 4000000}{64.32} = 12000000$ foot-pounds.

$12000000 \div 772 = 15544 +$ heat units.

$15544 \div 100 = 155.44$ heat units for each pound of water. This would raise the temperature 155.44° F., leaving it at 187.44° F. *Ans.*

(*b*.) Knowing the weight of the earth and its orbital velocity, we may easily compute the amount of heat that would be developed by the impact of the earth against a target strong enough to stop its motion. The heat thus generated from the *kinetic energy* of the earth would be sufficient to fuse if not vaporize it, equalling that derivable from the combustion of fourteen globes of coal each equal to the earth in size. After the stoppage of its orbital motion it would surely be drawn to the sun with continually increasing velocity. The heat instantaneously developed from this impact of the planetary projectile would equal that derivable from the combustion of 5600 globes of coal each equal to the earth in size. This is the measure of the *potential energy* of the earth considered as a mass separated from the sun.

633. Chemical Affinity.—We have already seen that there are forces in nature compared with which the force of gravity is insignificant. (Read carefully the first paragraph in this chapter.) When coal is burned, the carbon and oxygen particles rush together with tremendous violence, energy of position being converted into energy of motion. The molecular motions produced by this clashing of particles constitute heat and have a mechanical value.

634. Heat Equivalent of Chemical Union.—If a pound of carbon be burned, the heat of the combustion would raise about 8,000 pounds of water 1° C. In like manner, the combustion of a gram of hydrogen would yield about 34,000 lesser calories.

(*a.*) The following table shows the heating powers of several substances when burned in oxygen:

Hydrogen	34,462	Alcohol (C_2H_6O)	6,850
Marsh gas (CH_4)	13,063	Phosphorus	5,747
Petroleum	12,300	Carbon protoxide (CO)	2,403
Carbon	8,080	Sulphur	2,220

(*b.*) The calorific powers mentioned above may be adapted to Fahrenheit degrees by multiplying them respectively by $\frac{9}{5}$. As they stand, the numbers represent the number of times its own weight of water that could be warmed 1° C. by burning the substance in oxygen.

635. The Steam-Engine.—The steam-engine is a machine for utilizing the tension of steam. Its essential parts are a boiler for the generation of steam, and a cylinder for the application of the tension to a piston.

(*a.*) As in the case of water-power the production of mechanical kinetic energy involves the fall of water from a higher to a lower level, so in the case of steam-power the production of visible energy involves the fall of heat from a higher to a lower temperature.

636. Single-Acting Engine.—In a single-acting steam engine, the piston is pushed one way by the tension of the steam. The steam is then condensed and the piston driven back by atmospheric pressure. Such engines have gone out of use and have only an historical interest.

637. Double-Acting Engine.—In a double-acting steam-engine, the steam is admitted to the cylinder alternately above and below the piston. This alternate admission of the steam is accomplished by means of a sliding-valve. The sliding-valve is placed in a steam-chest, *S*, which is fastened to the side of the cylinder *C*.

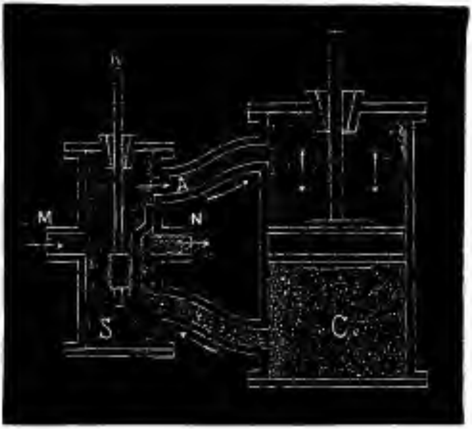


FIG. 315.

(*a.*) In the figure, the steam-chest is represented as being placed at a distance from the cylinder; this is merely for the purpose of making plain the communicating passages to and from the chest. Steam from the boiler enters at *M*, passes through *A* to the

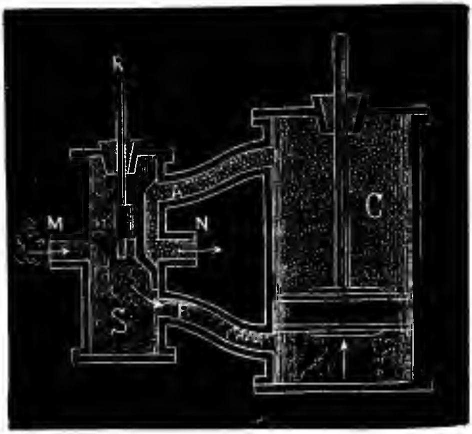


FIG. 316.

cylinder, where it pushes down the piston as indicated by the arrows. The steam below the piston escapes by *B* and *N*. As the piston nears the opening of *B* in the cylinder, the sliding-valve is raised, by means of the rod *R*, to the position indicated in Fig. 267. Steam now enters the cylinder by *B* and pushes up the piston. The steam above the piston escapes by *A* and *N*. As the piston nears the opening of *A* in the cylinder, the sliding-valve is pushed down by *R* and the process is thus repeated. The piston-rod and the sliding-valve rod work through steam-tight packing-boxes. (Appendix S.)

638. The Eccentric.—By means of a crank or similar device, illustrated in common foot-power machinery like the turning-lathe, scroll-saw, or sewing-machine, the alternating rectilinear motion of the piston-rod is changed into a continuous rotary motion. A circular shaft is thus given a revolution for every to-and-fro movement of the piston. This shaft generally carries an eccentric for working the sliding-valve rod *R*. The eccentric (Fig. 317) consists of a circular piece of metal, *e*, rigidly attached to the shaft of the engine *S*, in such a position that the centre of the piece does not coincide with the centre of the shaft.

The eccentric turns within a collar, which is fastened to the frame *T*. Every turn of the shaft moves the eccentric with its collar and the frame *T*, backward and forward into the two positions indicated by the full and dotted lines of

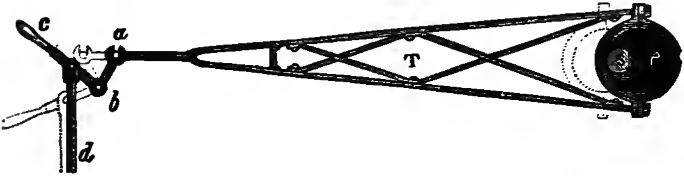


FIG. 317.

Fig. 317. The point *a* may be fastened directly to the sliding-valve rod or through the agency of the bent lever, *abc*, as the circumstances of the case render more desirable.

639. The Governor and Fly-Wheel.—The admission of steam through *M* (Fig. 316) is regulated by a throttle valve worked by a governor (Fig. 318). A vertical shaft is given a rotary motion by the machinery. To the top of this rod are hinged two arms carrying heavy balls, *bb*. From these arms, supports extend to a collar, *c*, surrounding the vertical rod. This collar is connected with a valve controlling the admission of steam to the valve-chest in such a way that when the collar rises the valve closes. As the machinery increases its speed, the balls revolve more rapidly about the vertical axis and tend to fly further apart (§ 74). In doing so, they raise the collar and partly close the valve, diminishing the supply of steam. The machinery is thus made to slacken its speed, the balls fall, and the valve opens. The rapidity of motion can therefore be confined within

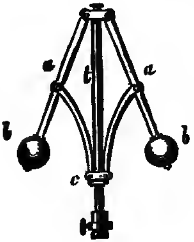


FIG. 318.

the limits due to closing the throttle-valve and throwing it wide open. Further than this, smoothness of motion is secured by attaching a heavy fly-wheel to the shaft of the engine. A little reflection will show that the fly-wheel also acts as an *accumulator of energy*.

640. The Safety-Valve.—The safety-valve is a necessary part of every steam-boiler. It consists of a valve, *V*, held down over an opening in the top of the boiler by means of a spring or a loaded lever of the second class. The force with which the valve is held down is to be less than the strength of the boiler, *i. e.*, the force must be such that the valve will open before the tension of the steam becomes dangerous. On steamboats, the weight, *W*, is generally *locked in position* by a Government officer.

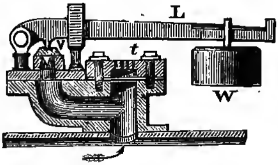


FIG. 319.

641. Non-Condensing Engines.—When the steam is forced out at *N* (Fig. 316), it has to overcome an atmospheric pressure of 15 pounds to the square inch. This must be deducted from the total tension of the steam to find the *available* power of the engine. Such an engine is known as a non-condensing engine. It may be recognized by the escape of steam in puffs. It is generally a high-pressure engine. The railway locomotive is a high-pressure, non-condensing engine.

(*a.*) Only a small part of the heat developed by the combustion of the fuel can be converted into mechanical energy by the engine. Most of it passes off in the exhaust steam, still existing as heat which is wasted, so far as useful effect is concerned. The ratio between the heat delivered to the engine and the heat converted for doing the work is called the *efficiency* of the engine. "It is not possible, even with a perfect engine, to convert into work more than 15 per cent. of the heat used."

642. Condensing Engines.—The steam may be conducted from the exhaust pipe, *N* (Fig. 316), to a chamber called a condenser. Steam from the cylinder and a jet of cold water being admitted at the same time, a vacuum is formed and the loss of energy due to atmospheric pressure is avoided. Such an engine is known as a condensing, or low-pressure engine.

(*a.*) Low-pressure engines are always condensing engines. A low-pressure engine will do more work with a given amount of fuel than a high-pressure, non-condensing engine will, is less liable to explosion, and causes less wear and tear to the machinery. But it must be larger, more complicated, more costly and less portable.

643. Heat and Work of Steam-Engines.—More heat is carried to the cylinder of a steam-engine than is carried from it. The piston does work at every stroke and this work comes from the heat that disappears. Every stroke of the piston annihilates heat. Careful experiments show that the heat destroyed and the work performed are in strict agreement with Joule's equivalent. With a given supply of fuel, the engine will give out less heat when it is made to work hard than when it runs without doing much work.

EXERCISES.

1. The mechanical equivalent of heat is 1,390 foot-pounds. What is it in kilogrammeters?

2. Find the weight of water that may be warmed 15° C. by burning 1 ounce of sulphur in oxygen. *Ans.* 148 oz.

3. What weight of water would be heated from 0° C. to 1° C. by the combustion of one gram of phosphorus? *Ans.* 5,747 *g.*

4. One gram of hydrogen is burned in oxygen. To what temperature would a kilogram of water at 0° C. be raised by the combustion?

5. From what height must a block of ice at 0° C. fall that the heat generated by its collision with the earth shall be just able to melt it?

6. From what height must it fall that the heat generated may be sufficient to vaporize it? *Ans.* 996,630 ft. *in vacuo.*

7. To what height could a ton weight be raised by utilizing all the heat produced by burning 5 lb. of pure carbon? *Ans.* 28,078 ft.

8. Find the height to which it could be raised if the coal had the following percentage composition:

$$C = 88.42;\quad H = 5.61;\quad O = 5.97.$$

9. To what temperature would a cannon-ball weighing 150 lb. and moving 1,920 feet per sec., warm 2,000 lb. of water at 32° F., if its motion were suddenly converted into heat? *Ans.* $37\frac{1}{2}$° F.

10. (*a.*) How many pounds of water can be evaporated by 80 lb. of pure carbon? (*b.*) If applied to iron, how many pounds could be heated from 0° F. to 2,000° F.? *Ans.* 1,203.72 lb.

11. With what velocity must a 10-ton locomotive move to give a mechanical energy equivalent to the heat necessary to convert 48 pounds of ice at 0° C. to steam at 100° C.? *Ans.* 392.8 ft.

12. An 8-lb. ball is shot vertically upward in a vacuum with a velocity of 2,000 feet. How many pounds of water may be raised from the freezing to the boiling point by the heat generated when it strikes the earth on its descent? *Ans.* 3.57 lb.

13. (*a.*) From what height must water fall in order to raise its own temperature 1° C. by the destruction of the velocity acquired, supposing no other body to receive any of the heat thus generated? (Answer to be given in meters.) (*b.*) How far must mercury fall to produce the same effect? (Specific heat of mercury = .0333.)

14. With a velocity of how many *cm.* per second must a leaden bullet strike a target that its temperature may be raised 100° C. by the collision, supposing all the energy of the motion to be spent in heating the bullet? (Specific heat of lead=.0314; g=980 *cm.* § 127.)

15. A steam-engine raises a ton weight 386 ft. How many calories are thus expended?

16. A 64-pound cannon-ball strikes a target with a velocity of 1,400 feet per second. Supposing all the heat generated to be given to 60 pounds of water, how many centigrade degrees would the temperature of the water be raised? *Ans.* 23.3.

17. A cannon-ball weighing 7 pounds strikes an iron target with a velocity of 1,000 feet per second. Suppose the whole of the motion to be converted into heat and the heat uniformly distributed through 70 pounds of the target, determine the change of temperature thus produced. (Specific heat of iron = .1138.) *Ans.* 17.7° C.

18. The specific heat of tin is .056 and its latent heat of fusion is 25.6 Fahrenheit degrees. Find the mechanical equivalent of the amount of heat needed to heat 6 pounds of tin from 374° F. to its melting point, 442° F., and to melt it. *Ans.* 136,217.856 foot-pounds.

Recapitulation.—In this section we have considered the definition of Thermodynamics; the Correlation of Heat and Mechanical Energy; heat from Percussion; from Friction; First Law of thermodynamics; Joule's Equivalent and its Use; Chemical Affinity and the Heating Powers of various substances; the Single and Double-acting Steam-engines; the Eccentric, Governor and Safety-valve; Condensing and Non-condensing Engines; the relation between Heat and Work in the steam-engine.

REVIEW QUESTIONS AND EXERCISES.

1. Lead melts at 326° C. In melting it absorbs about as much heat as would warm 5.37 times its weight of water 1° C. What numbers will replace the 326 and 5.37 when the Fahrenheit scale is used?

2. What is the difference between the temperatures —40° C. and —40° F.?

3. A quantity of gas at 100° C. and under a pressure of 750 *mm.* of mercury measures 4500 *cu. cm.* What will be its volume at 200° C. and under a pressure of 76 *cm.* of mercury? *Ans.* 5,631 *cu. cm.*

4. Over how high a ridge can you carry water in a siphon, where the minimum range of the barometer is 27 inches? Explain.

5. (*a.*) What is Specific Gravity? (*b.*) How do you find that of solids heavier than water? (*c.*) What principle is involved in your method?

6. (*a.*) Of what physical force is lightning a manifestation? (*b.*) Give some plain directions for the construction of lightning-rods, with reasons for your directions.

7. Give the fundamental principle of mechanics, and illustrate its application by one of the mechanical powers.

8. (*a.*) What are the essential properties of matter? (*b.*) What is a pendulum; (*c.*) to what use is it principally applied, and (*d.*) what are the laws by which it is governed?

9. (*a.*) In what ways may two musical tones differ? (*b.*) What is the physical cause of the difference in each case?

10. (*a.*) Convert —3° F. and 77° F. into C. readings; (*b.*) 18° C. and 20° C. to F. readings.

11. (*a.*) To what temperature should a liter of oxygen at 0° C. be raised in order to double its volume, the pressure remaining constant? (*b.*) Give reasons for your answer. *Ans.* 273° C.

12. (*a.*) What is meant by the boiling point of a liquid? (*b.*) State some circumstances that cause it to vary.

13. A kilogram each of water, iron and antimony, at 0° C. are heated ten minutes by the same source of heat, and are then found to be 1° C., 9° C. and 20° C. respectively. Required the specific heat of each.

14. (*a.*) Define latent heat. (*b.*) Describe a method of determining the latent heat of water. (*c.*) Describe the cooling and freezing of a lake.

15. (*a.*) If 2 kilograms of water should be suddenly stopped after falling 212 metres, how much heat would be generated? (*b.*) Describe the essential parts of a steam-engine.

16. (*a.*) How many cubic feet of water will be displaced by a boat weighing two tons? (*b.*) How many of salt water of sp. gr. 1.09? (*c.*) How does a noise differ from a musical sound?

17. The sp. gr. of alcohol is .8; that of mercury 13.6. When a mercury barometer indicates a pressure of 30 inches, what will be the height of an alcohol barometer column? *Ans.* 510 in.

18. (*a.*) Describe the ordinary force-pump; (*b.*) explain the use of its essential parts.

19. (*a.*) Give the formulas for changing thermometric readings from F. to C., and *vice versa.* (*b.*) Explain the graduation of two kinds of thermometers. (*c.*) Define increment of velocity.

20. (*a.*) What is distillation, and upon what fact does the process depend? (*b.*) What is latent heat? (*c.*) Illustrate the conversion of sensible into latent heat. (*d.*) On what does the pitch of sound depend?

21. (*a.*) Define boiling and boiling-point. (*b.*) What is the rate of expansion for gases? (*c.*) Will water boil at a lower temperature at the sea level or on the top of a mountain? Why? (*d.*) What constitutes the *timbre* of a sound? (*e.*) Give the formulas for the wheel and axle.

22. (*a.*) If the pressure remain the same, how much will 546 *cu. cm.* of hydrogen expand when heated from 0° C. to 10° C.? (*b.*) How much work may be performed by a ball weighing 64.32 lb., moving with a velocity of 50 ft. per second? (*c.*) When has water the greatest density? *Ans.* (*a.*) 20 *cu. cm.* (*b.*) 2,500 foot-pounds.

23, Show that to raise the temperature of a pound of iron from 0° C. to 100° C. requires more energy than to raise seven tons of iron a foot high.

CHAPTER IX.

LIGHT.

SECTION I.

THE NATURE, VELOCITY AND INTENSITY OF LIGHT.

644. What is Light?—*Light is that mode of motion which is capable of affecting the optic nerve. The only physical difference between light and radiant heat is one of wave length.*

(*a.*) We have seen that the vibrations of air particles in a sound wave are to and fro in the line of propagation. In the case of radiant heat and light, the ether particles vibrate to and fro across the line of propagation. Vibrations in a sound wave are *longitudinal;* those of a heat or light wave are *transversal.*

645. Luminous and Non-Luminous Bodies.—Bodies that emit light of their own generating, as the sun or a candle, are called luminous. Bodies that merely diffuse the light that they receive from other bodies are said to be non-luminous or illuminated. Trees and plants are non-luminous.

(*a.*) Visible bodies may be luminous or illuminated, but in either case they send light in every direction from every point in their surfaces. In Fig. 320 we see represented a few of the infinite number of lines of light starting from *A*, *B* and *C*, three of the infinite number of points in the surface of a visible object. *If the infinite number of lines were drawn from each of the infinite number of points,* there would be no vacant spaces in the figure; the rays really intersect at every point from which the object is visible.

FIG. 320.

646. Transparent, Translucent and Opaque Bodies.—Bodies are transparent, translucent or opaque according to the degree of freedom which they afford to the passage of the luminiferous waves. Transparent bodies allow objects to be seen distinctly through them, *e. g.*, air, glass and water. Translucent bodies transmit light, but do not allow bodies to be seen distinctly through them, *e. g.*, ground glass and oiled paper. Opaque bodies cut off the light entirely and prevent objects from being seen through them at all. The light is either reflected or absorbed. So much of the radiant energy as is neither reflected nor transmitted is changed to absorbed heat.

647. Luminous Rays.—A single line of light is called a ray. The ray of light is perpendicular to the wave of ether. The ray may, without considerable error, be deemed the path of the wave.

648. Luminous Beams and Pencils.—A collection of parallel rays constitutes a beam; a cone of rays constitutes a pencil. The pencil may be converging or diverging. If a beam or pencil should dwindle in thickness to a line, it would become a ray.

649. Rectilinear Motion of Light.—A medium is homogeneous when it has an uniform composition and density. *In a homogeneous medium, light travels* *in straight lines.* This is a fact of incalculable scientific and otherwise practical importance.

(*a.*) The familiar experiment of "taking sight" depends upon this fact, for we see objects by the light which they send to the eye. We cannot see around a corner or through a crooked tube. A beam of light that enters a darkened room by a small aperture, marks an illuminated course that is perfectly straight.

(*b.*) This fact may be illustrated by providing two or three perforated screens and arranging them as shown in Fig. 321, so that the holes and a candle flame shall be in the same straight line.

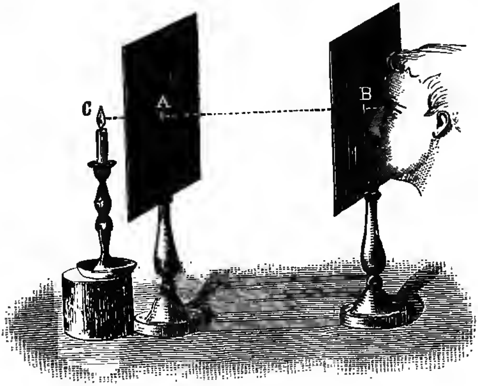


FIG. 321.

When the eye is placed in this line behind the screens, light passes from the flame to the eye; the flame is visible. A slight displacement upward, downward or sidewise of the eye, the flame or any screen, cuts off the light and renders the flame invisible.

(*c.*) Prepare a piece of wood, 1½ × 2½ × 18 inches, taking care that the edges are square. Saw it into six pieces, each three inches long. Prepare three pieces of wood, 3 × 4 × ⅛ inches. Place three postal cards one over the other on a board, and pierce them with a fine awl or stout needle, ½ inch from the end and 1½ inch from either side of the card. With a sharp knife pare off the rough edges of the holes, and pass the needle through each hole to make the edges smooth and even. Over the ½ × 3 inch surface of one of the blocks place the unperforated end of one of the postal cards, and over this place one of the 3 × 4 inch pieces, so that their lower edges shall be even. Tack them in this position. Make thus two more similar screens. The three screens, with a bit of candle three inches long, placed upon one of the remaining blocks, furnishes the material for the experiment above. Save the screens and three blocks for future use. (See Fig. 329.)

650. Inverted Images.—If light from a highly-illuminated body be admitted to a darkened room through a small hole in the shutter and there received upon a white screen, it will form an inverted image of the object upon the screen. Every visible point of the illuminated object sends a ray of light to the screen. Each ray brings the color of the point which sends it and prints the color upon the screen. As the rays are straight lines, they cross at the aperture; hence, the inversion of the image. The image will be distorted unless the screen be perpendicular to the rays. The darkened room constitutes a *camera obscura.* The image of the school playground at recess is very interesting and easily produced.

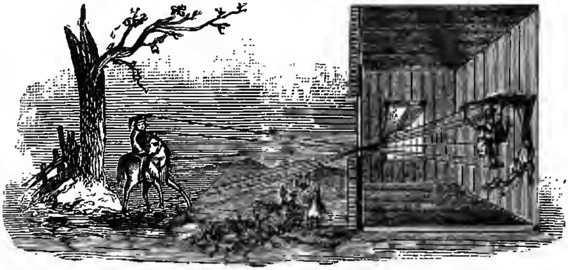


FIG. 322.

(*a.*) Place a lighted candle about a meter from a white screen in a darkened room. (The wall of the room will answer for the screen.) Pierce a large pin-hole in a card and hold it between the flame and the screen. An inverted image of the flame will be found upon the screen.

(*b.*) Bore an inch hole in one side of a wooden box; cover this opening with tin-foil and prick the tin-foil with a needle. Place a lighted candle within the box; close the box with a lid or a shawl and hold a paper screen before the hole in the tin-foil. Move the screen backward and forward and notice that in any position the size of the object is to the size of the image as the distance from the aperture to the object is to the distance from the aperture to the image.

(*c.*) Cover one end of a tube, 10 or 12 *cm.* long, with tin-foil; the other end with oiled paper. Prick a pin-hole in the tin-foil and turn it toward a candle flame. The inverted image may be seen upon the oiled paper. The size of the image will depend upon the distance of the flame from the aperture. The apparatus rudely represents the eye, the pin-hole corresponding to the pupil and the oiled paper to the retina. (Almost any housekeeper will give you an empty tin can. Place it upon a hot stove just long enough to melt off one end, thrust a stout nail through the centre of the other end, cover the nail-hole with tin-foil, and you will have the greater part of the apparatus.)

651. Shadows.—Since rays of light are straight, opaque bodies cast shadows. *A shadow is the darkened space behind an opaque body from which all rays of light are cut off.* It is sometimes called the perfect shadow or the umbra. If the source of light be a point, the shadow will be well defined; if it be a surface, the shadow will be surrounded by an imperfect shadow called a penumbra. The penumbra is the darkened space

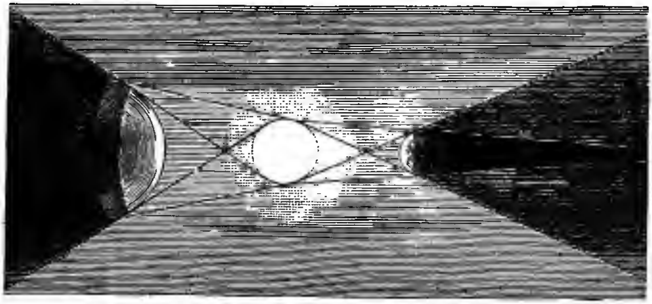


FIG. 323.

behind an opaque body from which some of the rays (the rays from a part of the luminous surface) are cut off.

(*a.*) Hold a lead pencil between the flame of an ordinary lamp and a sheet of paper held about two feet (61 *cm.*) from the lamp: (1.) When the *edge* of the flame is toward the pencil; (2.) When the *side* of the flame is toward the pencil.

652. Visual Angle.—*The angle included between two rays of light coming from the extremities of an object to the centre of the eye is called the visual angle.* This angle measures the apparent length of the line that subtends it. Any cause that increases the visual angle of an object increases its apparent size. Hence the effect of magnifying-glasses. From Fig. 324 we see that equal lines may subtend different visual angles, or that different lines may subtend the same angle.

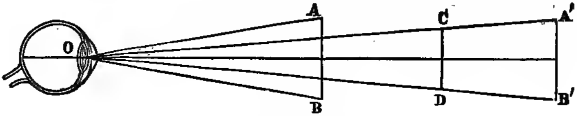


FIG. 324.

653. Velocity of Light.—Light traverses the ether with a velocity of about 186,000 miles or about 298 million meters per second. This was first determined about 200 years ago by Roemer, a Danish astronomer.

(*a.*) At equal intervals of 42h. 28m. 36s., the nearest of Jupiter's satellites passes within his shadow and is thus eclipsed. This phenomenon would be seen from the earth at equal intervals if light traveled instantaneously from planet to planet. Roemer found that when the earth was farthest from Jupiter the eclipse was seen 16 min. 36 sec. later than when the earth was nearest Jupiter. But Jupiter and the earth are nearest each other when they are on the same side of the sun and in a straight line with the sun (conjunction), and farthest from each other when they are on opposite sides of the sun and in a straight line with that luminary (opposition). Hence, Roemer argued that it requires 16 min. 36 sec. for light to pass over the diameter of the earth's orbit, from E to E'. This distance being approximately known, the velocity of light is easily computed.

FIG. 325.

(*b.*) The velocity of light has been measured by other means, giving results that agree substantially with the result above given. When astronomers accurately determine the mean distance of the earth from the sun, the velocity of light will be accurately known.

(*c.*) It would require more than 17 years for a cannon-ball to pass over the distance between the sun and the earth; light makes the journey in 8 min. 18 sec. For the swiftest bird to pass around the earth would require three weeks of continual flight; light goes as far in less than one seventh of a second. For terrestrial distances, the passage of light is practically instantaneous (§ 487).

654. Effect of Distance upon Intensity.—

The intensity of light received by an illuminated body varies inversely as the square of its distance from the source of light.

(*a.*) Let a candle at S be the source of light; A, a screen one foot square and a yard from S; B, a screen two feet square two yards from S; C, a screen three feet square three yards from S. It will easily be seen that A will cut off all the light from B and C. If now A be removed, the quantity of light which it received, no more and no less, will fall upon B. If now B be removed, the quantity of light which previously illuminated A and B will fall upon C. We thus see the same number of rays successively illu minating, one, four and nine square feet. One square foot at *B* will receive one-fourth, and one square foot at *C* will receive one-ninth as many rays as one square foot at *A*. The light being diffused over a greater surface is correspondingly diminished in intensity.

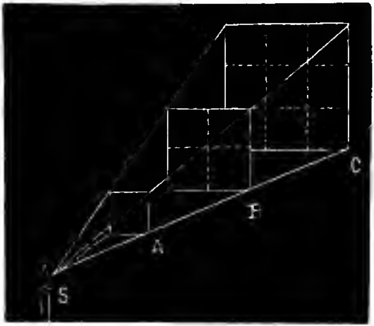


FIG. 326.

(*b.*) The experiment may be tried by placing the large screen at *A* and tracing the outline of the shadow with a pencil, then placing the screen successively at *B* and *C*, tracing the shadow each time. The experiment will be more satisfactory if a perforated screen be placed at *S*. (See *First Principles*, § 428.)

EXERCISES.

1. A coin is held 5 feet from a wall and parallel to it. A luminous point, 15 inches from the coin, throws a shadow of it upon the wall. How does the size of the shadow compare with that of the coin?

2. (*a.*) What is the velocity of light? (*b.*) How was it determined?

3. (*a.*) How are the intensities of two lights compared? (*b.*) Define light. (*c.*) Give your idea of the carrier of radiant heat and light.

4. (*a.*) Define luminous, transparent, opaque, beam and pencil. (*b.*) How could you show that light ordinarily moves in straight lines? (*c.*) Explain the formation of inverted images in a dark room.

5. A "standard" candle (burning 120 grains of sperm *per* hour) is 2 feet from a wall, a lamp is 6 feet from the wall. They cast shadows of equal intensity on the wall. What is the "candle power" of the lamp?

Recapitulation.—In this section we have considered the Nature of Light; Luminous, Illuminated, Transparent, Translucent and Opaque bodies; Rays, Beams and Pencils of light; that Light Moves in Straight Lines; Inverted Images and Shadows; the Visual Angle; the Velocity and Intensity of light.

SECTION II.

REFLECTION OF LIGHT.

Note.—The heliostat, or *porte-lumière*, is composed of one or more mirrors, by means of which a beam of light may be thrown in any desired direction. The instrument may be had of apparatus manufacturers at prices ranging from $12 upward. Directions for making one may be found in Mayer & Barnard's little book on "Light," published by D. Appleton & Co. It is very desirable that the instrument be secured in some way.

655. Reflection.—If a sunbeam enter a darkened room by a hole in the shutter, as at *A*, and fall upon a polished plane surface, as at *B*, it will be continued in a different direction, as toward *C*. *AB* is called the incident beam and *BC* the reflected beam (§ 97). The incident and the reflected beams are in the same medium, the air. *A change in the direction of light without a change in its medium is called reflection of light.*

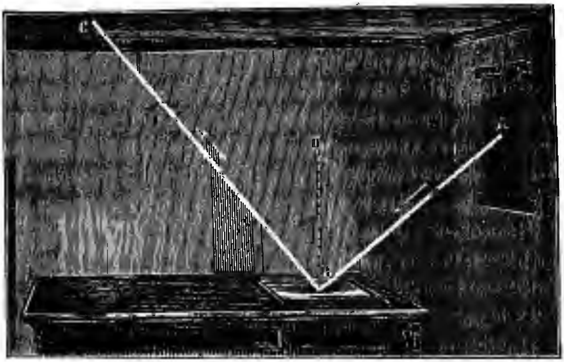


FIG. 327.

656. Laws of Reflection.—The reflection of light from polished surfaces is in accordance with the following laws:

(1.) *The angle of incidence is equal to the angle of reflection.*

(2.) *The incident and reflected rays are both in the same plane, which is perpendicular to the reflecting surface.*

(*a.*) Fill a basin to the brim with mercury or with water blackened with a little ink. In this liquid suspend by a thread a small weight of greater specific gravity than the liquid used (§ 253). The plumb-line will be perpendicular to the liquid mirror. Let the plumb-line hang from the middle of a horizontal meter or yard-stick. Place the tip of a candle flame opposite one of the divisions of the stick, and place the eye in such a position that the image of the top of the flame will be seen in the direction of the foot of the plumb-line. Mark the point where the line of vision (*i. e.*, the reflected rays) crosses the meter-stick. It will be found that this point and the tip of the flame are equally distant from the middle of the stick. From this it follows (*Olney's Geometry*, Art. 342) that the angles of incidence and of reflection are equal.

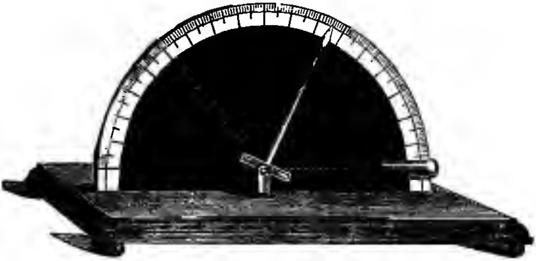


FIG. 328.

(*b.*) Fig. 328 represents a vertical semicircle graduated to degrees, with a background of black velvet. A mirror at the centre is furnished with an index set perpendicular to its plane; both mirror and index can be turned in any direction desired. A ray of light from any brilliant source is allowed to enter the tube at the base, in the direction of the centre. By means of a little smoke from brown paper, the paths of the incident and reflected rays are easily shown to a large class.

(*c*.) Place two of the screens and the three extra blocks mentioned in § 649 in position, as shown in Fig. 329. At the middle of the middle block place a bit of window glass, painted on the under side with black varnish. On the blocks that carry the screens place bits of glass, *n* and *o*, of the same thickness as the black mirror on the middle block. Place a candle flame near the hole in one of the screens, as shown in the figure. Light from the candle will pass through *A*, be reflected at *m*, and pass through *B*. Place the eye in such a position that the spot of light in the mirror may be seen through *B*. Mark the exact spot in the mirror with a needle held in place by a bit of wax. Place a piece of stiff writing paper upright upon *m* and *n*, mark the position of *B* and of *m*, and draw on the paper a straight line joining these two points. The angle between this line and the lower edge of the paper coincides with the angle *Bmn*. Reverse the paper, placing it upon *m* and *o*. It will be found that the same angle coincides with *Amo*. *Amo* and *Bmn* being thus equal, the angle of incidence equals the angle of reflection.

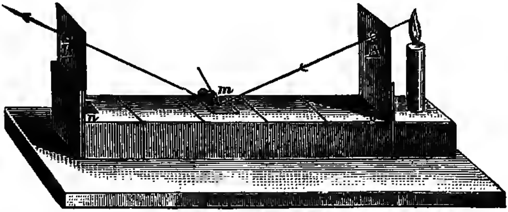


FIG. 329.

657. Diffused Light.—Light falling upon an opaque body is generally divided into three parts: the first is regularly reflected in obedience to the laws above; the second is irregularly reflected or diffused; the third is absorbed. The irregular reflection is due to the fact that the bodies are not perfectly smooth, but present little protuberances that scatter the light in all directions, and thus render them visible from any position. Light regularly reflected gives an image of the body from which it came before reflection; light irregularly reflected gives an image of the body that diffuses it. A perfect mirror would be invisible. *Luminous bodies are visible on account of the light that they emit; non-luminous bodies are visible on account of the light that they diffuse.*

(*a.*) If a beam of light fall upon a sheet of drawing paper, it will be scattered and illuminate a room. If it fall upon a mirror, nearly all of it will be reflected in a definite direction, and intensely illuminate a part of the room. Place side by side upon a board a piece of black cloth (not glossy), a piece of drawing paper and a piece of looking-glass. In a darkened room, allow a beam of sunlight to fall upon the cloth and notice the absorption. Let it fall upon the paper, and notice the diffusion of the light and its effects. Let it fall upon the looking-glass, and notice the regular reflection and its effects. Move the board so that the cloth, paper and glass shall pass through the beam in quick succession, and notice the effects.

(*b.*) In the darkened room place a tumbler of water upon a table; with a hand-mirror reflect a sunbeam down into the water; the tumbler will be visible. Stir a teaspoonful of milk into the water, and again reflect the sunbeam into the liquid; the whole room will be illuminated by the diffused light, the tumbler of milky water acting like a luminous body.

658. Invisibility of Light.—*Rays of light that do not enter the eye are invisible.* A sunbeam entering a darkened room is visible because the floating dust reflects some of the rays to the eye. If the reflecting particles of dust were absent the beam would be invisible.

(*a.*) Take any convenient box, about 60 *cm.* (2 *ft.*) on each edge, provide for it a glass front, and, at each end, a glass window about 10 *cm.* (4 inches) square. Place it on a table in a darkened room, and, with the heliostat, send a solar beam through the windows. Standing before the glass front of the box, this beam may be traced from the heliostat to the box, through the box and beyond it. Open the box, smear the inner surfaces of its top, back and bottom with glycerine, and close the box air-tight. Allow it to remain quiet a few days; the dust in the box will be caught by the glycerine and the confined air thus freed from particles capable of reflecting light. Then send another solar beam from the heliostat through the two windows of the box. Standing as before, the beam may be traced to the box and beyond it, but within the box all is darkness.

659. Apparent Direction of Bodies.—Every point of a visible object sends a cone of rays to the eye. The pupil of the eye is the base of the cone. *The point always appears at the place where these rays seem to intersect* (*i. e.,* at the real or apparent apex of the cone). If the rays pass in straight lines from the point to the eye, the apparent position of the point is its real position. If these rays be bent by reflection, or in any other manner, *the point will appear to be in the direction of the rays as they enter the eye.* No matter how devious the path of the rays in coming from the point to the eye, this important rule holds good.

660. Plane Mirrors; Virtual Images.—If an object be placed before a mirror, an image of it appears behind the mirror. Inasmuch as the rays of the cone mentioned in § 659 do not actually converge back of the mirror, there can be no *real* image there. As there really is no image behind the mirror, we call it a *virtual* image. All virtual images are optical illusions, and are to be clearly distinguished from the *real* images to be studied soon. *Each point of this image will seem to be as far behind the mirror as the correspond-*

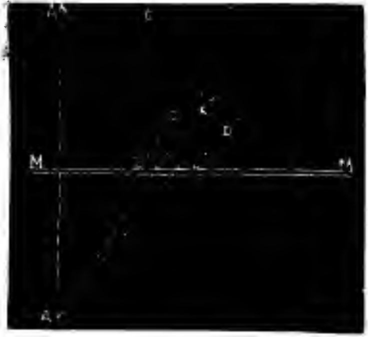


FIG. 330.

ing point of the object is in front of the mirror. Hence, images seen in still, clear water are inverted.

(*a.*) In Fig. 330, let A represent a luminous point; MM, a mirror; AA' and BC, lines perpendicular to the mirror. Rays from A enter the eye at DD'. The angle $ABC =$ the angle CBD (§ 656). The angle $ABC =$ the angle BAA' (*Olney's Geometry*, Art. 150). Therefore the angle $CBD =$ the angle BAA'. The angle $CBD =$ the angle $BA'A$ (*Olney*, 152). Therefore the angle $BAA' =$ the angle $BA'A$. Hence $AM = A'M$ (*Olney*, 287). In other words, A' is as far behind the mirror as A is in front of it.

(*b.*) Place a jar of water 10 or 15 *cm.* back of a pane of glass placed upright on a table in a dark room. Hold a lighted candle at the same distance in front of the glass. The jar will be seen by light transmitted through the glass. An image of the candle will be formed by light reflected by the glass. The image of the candle will be seen in the jar, giving the appearance of a candle burning in water. The same effect may be produced in the evening by partly raising a window and holding the jar on the outside and the candle on the inside.

661. Reflection of Rays from Plane Mirrors.—If the incident rays be parallel, the reflected rays will be parallel. If the incident rays be diverging, the reflected rays will be diverging; they will seem to diverge from a point as far behind the reflecting surface as their source is in front of that surface (See Fig. 330). If the incident rays be converging, the reflected rays will be converging; they will converge at a point as far in front of the mirror as the point at which they were tending to converge is behind the mirror.

662. Construction for the Image of a Plane Mirror.—The position of the image of an object may be determined by locating the images of several well-chosen points in the object and connecting these images.

(*a.*) In Fig. 331, let AB represent an arrow; MN, the reflecting surface of a plane mirror, and E the eye of the observer. From

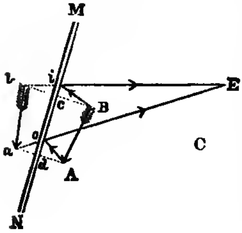


FIG. 331.

A, draw *Aa* perpendicular to *MN* and make *ad* equal to *Ad*. Then will *a* indicate the position of the image of *A*. From *B*, draw *Bb* perpendicular to *MN* and make *bc* equal to *Bc*. Then will *b* indicate the position of the image of *B*. By connecting *a* and *b* we locate the image of *AB*. Draw *aE*, *bE*, *Ao* and *Bi*. *AoE* represents one ray of the cone of rays from *A* that enters the eye; *BiE* represents one ray of a similar cone from *B*. Draw a similar figure on a larger scale, representing the eye at *C*. Test your figure by seeing if the angle of incidence is equal to the angle of reflection. In all such constructions, represent the direction of the rays by arrow-heads, as shown in Fig. 331.

663. Multiple Images.—By placing two mirrors facing each other, we may produce multiple images of an object placed between them. *Each image acts as a material object with respect to the other mirror, in which we see an image of the first image.* When the mirrors are placed so as to form an angle with each other, the number of images becomes limited, being one less than the number of times that the included angle is contained in four right angles. The mirrors will give three images when placed at an angle of 90°; five at 60°; seven at 45°.

(*a*.) When the mirrors are placed at right angles the object and the three images will be at the corners of a rectangle as shown at *A*, *a*, *a′* and *a″*.

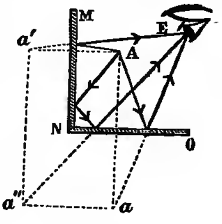


FIG. 332.

664. Concave Mirrors.—A spherical concave mirror may be considered as a small part of a spherical shell with its inner surface highly polished. Let *MN* (Fig. 333) represent the section of such a concave spherical mirror, and *C* the centre of the corresponding sphere. *C* is called the *centre of curvature;* *A* is the centre of the mirror. A straight line of indefinite length drawn from *A* through *C*, as *ACX*, is called the *principal axis* of the mirror. A straight line drawn from any other point of the mirror through *C*, as *JCd*, is called a *secondary axis.* The point *F*, midway between *A* and *C*, is called the *principal focus.* The distance *AF* is the focal distance of the mirror; the focal distance is, therefore, one-half the radius of curvature. The angle *MCN* is called the aperture of the mirror.

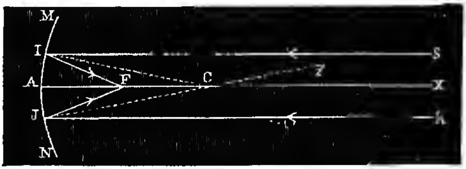


FIG. 333.

(*a.*) A curved surface may be considered as made up of an infinite number of small plane surfaces. Thus, a ray of light reflected from any point on a curved mirror may be considered as reflected from a plane tangent to the curved surface at the point of reflection. This reflection then takes place in accordance with the principles laid down in § 656. It should be borne in mind that the radii drawn from *C* to points in the mirror as *I* and *J* are perpendicular to the mirror at these points. Thus, the angles of incidence and reflection for any ray may be easily determined.

665. Effect of Concave Mirrors.—*The tendency of a concave mirror is to increase the convergence or to decrease the divergence of incident rays.*

(*a.*) If the divergence be that of rays issuing from the principal focus, the mirror will exactly overcome it and reflect them as parallel rays. If the divergence be greater than this, viz., that of rays issuing from a point nearer the mirror than the principal focus, the mirror cannot wholly overcome the divergence, but will diminish it.

The reflected rays will still diverge, but not so rapidly as the incident rays. If the divergence be less than that first mentioned, viz., that of rays issuing from a point further from the mirror than the principal focus, the divergence will be changed to convergence and a real focus will be formed.

666. The Principal Focus.—The focus of a concave mirror is the point toward which the reflected rays converge. All incident rays parallel to the principal axis will, after reflection, converge at the principal focus. *The principal focus is the focus of rays parallel to the principal axis.* The rays will be practically parallel when their source is at a very great distance, *e. g.*, the sun's rays. Solar rays coming to the human eye do not diverge a thousandth of an inch in a thousand miles.

(*a.*) Above we stated that parallel rays would be made to converge at the principal focus of a spherical concave mirror. This is only approximately true; it is strictly true in the case of a parabolic mirror. In order that the difference between the spherical and the parabolic mirror may be reduced to a minimum, the aperture of a spherical mirror must be small. The case is somewhat analogous to the coincidence of a circular arc of small amplitude with the cycloidal curve (§ 144, *a*). A source of light placed at the focus of a parabolic mirror will have its rays reflected in truly parallel lines. The head lights of railway locomotives are thus constructed. Parabolic mirrors would be more common if it were not so difficult to make them accurately.

667. Conjugate Foci.—Rays diverging from a luminous point in front of a concave spherical mirror and at a distance from the mirror greater than its focal distance, will converge, after reflection, at another point. The focus thus formed will be in a line drawn through the luminous point and the centre of curvature. In other words, if the luminous point lie in the principal axis, the focus will also; if the luminous point lie in any secondary axis, the focus will lie in the same secondary axis. The distinction between principal and secondary axes is almost wholly one of convenience. Rays diverging from *B* will form a focus at *b*. The angle of incidence being necessarily equal to the angle of reflection, it is evident that rays diverging from *b* would form a focus at *B*. On account of this relation between two such points, they are called conjugate foci. Therefore, *conjugate foci are two points so related that each forms the image of the other.*

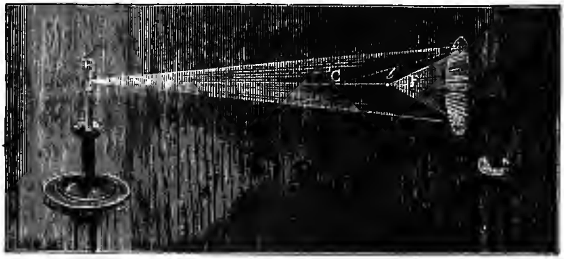


FIG. 334.

668. Construction for Conjugate Foci.—In the case of concave mirrors, to locate the conjugate focus of a luminous point, it is necessary to find the point at which at least two reflected rays really or apparently intersect. The method may be illustrated as follows:

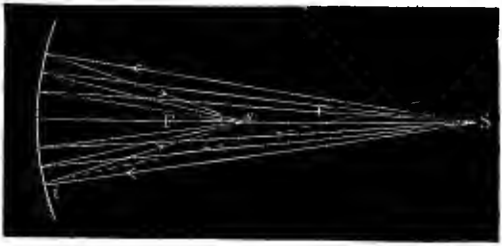


FIG. 335.

(1.) Let *S* (Fig. 335) represent the luminous point whose conjugate focus is to be located. It may or may not lie in the principal axis. Draw the axis for the point *S*, *i.e.*, a line from *S* through *C*, the centre of curvature, to the mirror. This line represents one of the infinite number of rays sent from *S* to the mirror. As this incident ray is perpendicular to the mirror, the reflected ray will coincide with it. (Angles of incidence and of reflection = 0.) The conjugate focus must therefore lie in a line drawn through *S* and *C*. Draw a line representing some other ray, as *Si*. From *i*, the point of incidence, draw the dotted perpendicular *iC*. Construct the angle *Cis* equal to the angle *CiS*. Then will *is* represent the direction of the reflected ray. The focus must also lie in this line. The intersection of this line with the line drawn through *SC* marks the position of *s*, the conjugate focus of *S*.

(2.) If the reflected rays be parallel, of course no focus can be formed. If they be divergent, produce them back of the mirror as dotted lines (Fig. 336) until they intersect. In this case the focus will be virtual, because the rays only seem to meet. In the other cases the focus was real, because the rays actually did meet.

FIG. 336.

(3.) With a radius of 4 *cm.*, describe ten arcs of small aperture to represent the sections of spherical concave mirrors. Mark the centres of curvature and principal foci, and draw the principal axes. Find the conjugate foci for points in the principal axis designated as follows: (1.) At a distance of 1 *cm.* from the mirror. (2.) Two *cm.* from the mirror. (3.) Three *cm.* from the mirror. (4.) Four *cm.* from the mirror. (5.) Six *cm.* from the mirror. Make five similar constructions for points not in the principal axis. Notice that each effect is in consequence of the equality between the angle of incidence and the angle of reflection.

669. Formation of Images.—Concave mirrors give rise to two kinds of images, real and virtual. After learning what has been said concerning conjugate, real and virtual foci, the formation of these images will be easily understood. The image of an object is determined by finding the images of a number of points in the object.

670. Construction for Real Images Formed by Concave Mirrors.—(1.) The method may be illustrated as follows: Let *AB* represent an object in front of a concave mirror, at a distance greater than the radius of curvature. Draw *Ax*, the secondary axis for the point *A*. The conjugate focus of *A* will lie in this line (§ 668 [1]). From the infinite number of rays sent from *A* to the mirror, select, as the second, the one that is parallel to the principal axis. This ray, after reflection at *i*, will pass through the principal focus (§ 666). The reflected rays, *iF* and *xA* (secondary axis for *A*), will intersect at *a*, which is the conjugate focus for *A*. In similar manner, *b*, the conjugate focus for *B*, may be found. Points between *A* and *B* will have their conjugate foci between *a* and *b*.

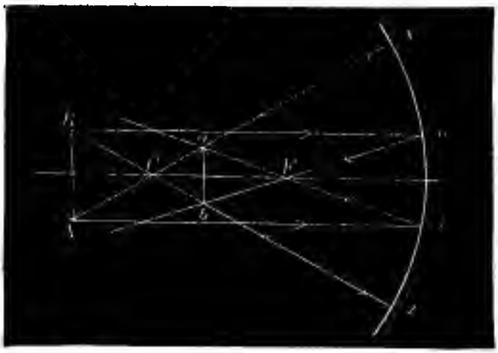


FIG. 337.

(2.) If the eye of the observer be placed far enough back of the image thus formed for all of the image to lie between the eye and the mirror, it will receive the same impression from the reflected rays as if the image were a real object. All of the rays from any point in the object, as *A*, that fall upon the mirror, intersect after reflection at *a*, the conjugate focus. These reflected rays, after intersecting at *a*, form a divergent pencil. A cone of these rays thus diverging from *a* enters the eye. They originally diverged from *A*, but *as they enter the eye*, they diverge from *a*. Hence the effect produced (§ 659).

(3.) From the similar triangles, *ABC* and *abC*, it is evident that the linear dimensions of the object and of its image are directly proportional to their distances from the centre of curvature. It may also be proved that the length of the object is to the length of the image as the distance of the object from the principal focus is to the focal distance of the mirror.

(4.) Since the lines that join corresponding points of object and image cross at the centre of curvature, the real images formed by concave mirrors are always inverted.

FIG. 338.

671. Projection of Real Images by Concave Mirrors.—The real image formed by a concave mirror may be rendered visible even when the eye of the observer is not in the position mentioned in the last article, by projecting it upon a screen. In a darkened room, let a candle flame be placed in front of a concave mirror, at a distance from it greater than the focal distance. Incline the mirror so that the flame shall not be on the principal axis. Place a paper screen at the conjugate focus of any point in the luminous object. The proper position for the screen may easily be found by trial. Shield the screen from the *direct* rays of the flame by a card painted black. The inverted image may be seen by a large class. If the image fall between the mirror and the candle, the screen should be quite small. (See *First Principles,* Fig. 205.)

672. Description of Real Images Formed by Concave Mirrors.—(1.) If the object be at the principal focus there will be no image. Why? (You can find out by trying a construction for the image (§ 670). (2.) If the object be between the principal focus and the centre of curvature, the image will be beyond the centre, inverted and enlarged. The nearer the object is to the principal focus, the larger and the further removed the image will be. (3.) When the object is at the centre, the image is inverted, of the same size as the object and at the same distance from the mirror. (4.) When the object is not very far beyond the centre of curvature, the image will be inverted, smaller than the object, and between the centre and the principal focus. (5.) When the object is at a very great distance, all of the rays will be practically parallel; there will be but one focus, and consequently no image.

(*a.*) For each of these five cases construct the images. The third case may be prettily illustrated as follows: In front of the mirror, at a distance equal to the radius of curvature, place a box that is open on the side toward the mirror. Within this box hang an inverted bouquet of bright-colored flowers. The eye of the observer is to be in the position mentioned in § 670 (2). By giving the mirror a certain inclination, easily determined by trial, an image of the invisible bouquet will be seen just above the box. A glass vase may be placed upon the box so that it may seem to hold the imaged flowers.

673. Construction for Virtual Images formed by Concave Mirrors.—Let *AB* represent an object in front of a concave mirror at a distance from it less than the focal distance. Draw the secondary axes for the points *A* and *B*, and produce them back of the mirror as dotted lines. From *A* and *B*, draw the incident rays *Ao* and *Bi*, parallel to the principal axis. After reflection they will pass through the principal focus (§ 666). Produce these rays back of the mirror as dotted lines until they intersect the prolongations of the secondary axes at *a* and *b*, which will be the virtual conjugate foci for *A* and *B*. The conjugate foci for other points in *AB* will be between *a* and *b*. Therefore, if the object be between the principal focus and the mirror, the image will be virtual, erect and enlarged.

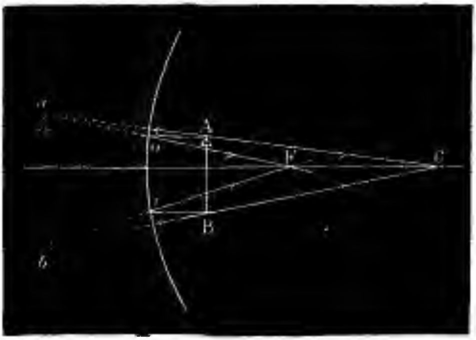


FIG. 339.

674. Images of the Observer formed by a Concave Mirror.—A person at a considerable distance before a concave mirror, sees his image, real, inverted and smaller than the object. As he approaches the centre of curvature, the image increases in size. As the observer moves from the centre to the principal focus, the image is formed back of him and is, therefore, invisible to him. As he moves from the principal focus toward the mirror, the image becomes virtual, erect and magnified, but gradually growing smaller. The eye will not always recognize real images as being in front of the mirror. It may sometimes be aided in this respect by extending the outspread fingers between the image and the mirror.

675. Convex Mirrors.—In convex mirrors, the foci are all virtual; the images are virtual, erect and smaller than their objects. The foci may be found and the images determined by the means already set forth. The construction is made sufficiently plain by Fig. 340.

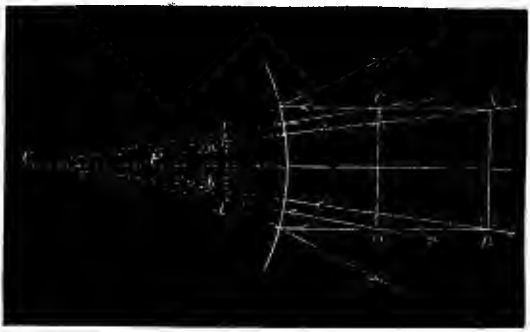


FIG. 340.

Note.—In constructions for curved mirrors, we have chosen two particular rays for each focus sought; one perpendicular to the mirror, the other parallel to the principal axis. This was only for the sake of convenience. Any two or more incident rays might have been taken and the direction of the reflected rays determined by making the angle of reflection equal to the angle of incidence.

EXERCISES.

1. What must be the angle of incidence that the angle between the incident and the reflected rays shall be a right angle?

2. The radius of a concave mirror is 18 inches. Determine the conjugate focus for a point on the principal axis, 12 inches from the mirror.

3. (*a.*) Illustrate by a diagram the image of an object placed at the principal focus of a concave mirror; (*b.*) of one placed between that focus and the mirror; (*c.*) of one placed between the focus and the centre of the mirror.

4. (*a.*) What kind of mirror always makes the image smaller than the object? (*b.*) What kind of a mirror may make it larger or smaller, and according to what circumstances?

5. Rays parallel to the principal axis fall upon a convex mirror. Draw a diagram to show the course of the reflected rays.

6. (*a.*) Why do images formed by a body of water, appear inverted? (*b.*) What is the general effect of concave mirrors upon incident rays?

7. A person, placed at a considerable distance before a concave mirror, sees his image. (*a.*) How does it appear to him? He approaches the mirror and the image changes. (*b.*) Describe the changes that take place until he sees a virtual image of himself.

8. A man stands before an upright plane mirror and notices that he cannot see a complete image of himself. (*a.*) Could he see a complete image by going nearer the mirror? Why? (*b.*) By going further from it? Why?

9. When the sun is 30° above the horizon, its image is seen in a tranquil pool. What is the angle of reflection?

10. A person stands before a common looking-glass with the left eye shut. He covers the image of the closed eye with a wafer on the glass. Show that when, without changing his position, he opens the left and closes the right eye, the wafer will still cover the image of the closed eye.

11. The distance of an object from a convex mirror is equal to the radius of curvature. Show that the length of the image will be one-third that of the object.

Recapitulation.—In this section we have considered the Nature and Laws of Reflection; Diffused and Invisible light; the Apparent Direction of bodies; Images formed in Plane Mirrors and their Construction; Concave Mirrors, their Effects, Principal and Conjugate Foci; Images formed by them with their Construction, Projection and Description; foci and images for Convex Mirrors.

SECTION III.

REFRACTION OF LIGHT

676. Preparatory.—So far, we have considered only that part of the incident beam that is turned back from the reflecting surface. As a general thing, a part of the beam enters the reflecting substance, being rapidly absorbed when the substance is opaque and freely transmitted when the substance is transparent. We have now to consider those rays that enter a transparent substance.

(*a.*) Procure a clear glass bottle with flat sides, about 4 inches (10 *cm.*) broad. On one side paste a piece of paper, in which a circular hole has been cut. On this clear circular space, draw two ink-marks at right angles to each other, as shown in Fig. 341. Fill the bottle with clear water up to the level of the horizontal ink-mark. Hold it so that a horizontal sunbeam from the heliostat may pass through the clear sides of the bottle above the water, and notice that the beam passes through the bottle in a straight line. Raise the bottle so that the beam shall pass through the water, and notice that the beam is still straight. In a card, cut a slit about 5 *cm.* long and 1 *mm.* wide. Place the card against the bottle as shown in the figure. Reflect the beam through this slit so that it

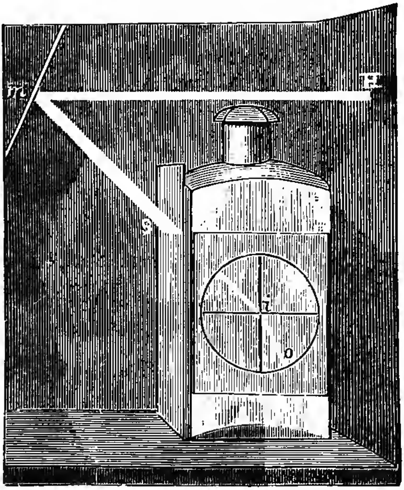


FIG. 341.

shall fall upon the surface of the water at *i*, the intersection of the two ink-marks. Notice that the reflected beam is straight until it reaches the water, but that it is bent as it obliquely enters the water.

677. Refraction.—*Refraction of light is the bending of a luminous ray when it passes from one medium to another.*

678. Index of Refraction.—If a ray of light from *L* (Fig. 342) fall upon the surface of water at *A*, it will be refracted as shown in the figure. The angle *LAB* is the angle of incidence and *KAC* the angle of refraction, *BC* being perpendicular to the water's surface. From *A* as a centre, with a radius equal to unity, describe a circle. From the points *m* and *p*, where this circle cuts the incident and refracted rays, draw *mn* and *pq* perpendicular to *BC*. Then will *mn* be the sine of the angle of incidence and *pq* the sine of the angle of refraction. *The quotient arising from dividing the sine of the angle of incidence by the sine of the angle of refraction is called the index of refraction for the two media.* It is evident that the greater the refractive power of the substance, the less the value of the divisor *pq*, and the greater the value of the quotient, the index of refraction.

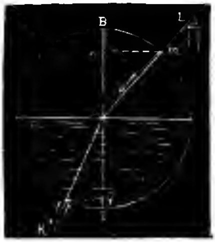


FIG. 342.

(*a.*) The following table gives the indices of refraction when light passes from a vacuum into any of the substances named :

Air	1.000294	Flint glass	1.575
Water	1.336	Carbon bisulphide	1.678
Alcohol	1.374	Diamond	2.439
Crown glass	1.534	Lead chromate	2.974

The index of refraction for any two media may be found by dividing the absolute index of one, as given above, by the absolute index of the other.

679. Laws of Refraction of Light.—(1.) *When light passes perpendicularly from one medium to another it is not refracted.*

(2.) *When light passes obliquely from a rarer to a denser medium* it is refracted toward a line drawn, at the point of incidence, perpendicular to the refracting surface, or, more briefly, *it is refracted toward the perpendicular.*

(3.) *When light passes obliquely from a denser to a rarer medium, it is refracted from the perpendicular.*

(4.) The incident and refracted rays are in the same plane which is perpendicular to the refracting surface.

(5.) The index of refraction is constant for the same two media.

680. Illustrations of Refraction.—Put a small coin into a tin cup and place the cup so that its edge just intercepts the view of the coin. A ray of light coming from the coin toward the observer must pass above his eye and thus be lost to sight. If, now, water be gradually poured into the cup, the coin will become visible. The rays are bent down as they emerge from the water and some of them enter the eye. For the same reason, an oar or other stick half immersed in water seems bent at the water's surface, while rivers and ponds whose bottoms

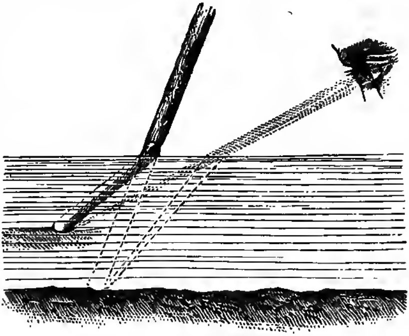


FIG. 343.

are visible are generally deeper than they seem to be. (Fig. 343.) As air expands, its index of refraction becomes less. Hence the indistinctness and apparent unsteadiness of objects seen through air rising from the surface of a hot stove. Light is refracted as it enters the earth's atmosphere. Hence the heavenly bodies appear to be further above the horizon than they really are except when they are overhead.

681. Total Reflection. — When a ray of light passes from a rarer into a denser medium, it may always approach the perpendicular so as to make the angle of refraction less than the angle of incidence (§ 679 [2]). But when a ray of light attempts to pass from a denser into a rarer medium there are conditions under which the angle of refraction cannot be greater than the angle of incidence. *Under such circumstances the ray cannot emerge from the denser medium, but will be wholly reflected at the point of incidence.* Fig. 344 represents luminous rays emitted from *A*, under water, and seeking a passage into air. Passing from the perpendicular, the angle of refraction increases more rapidly than the angle of incidence until one ray is found that emerges and grazes the surface of the water. Rays beyond this cannot emerge at all.

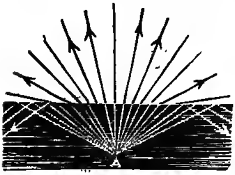


FIG. 344.

682. The Critical Angle. — Imagine a spherical (Florence) flask half filled with water. A ray of light from *L* will be refracted at *A* in the direction of *R*. If the angle of incidence, *CAL*, be

FIG. 345.

gradually increased the angle of refraction will be gradually increased until it becomes 90°, when the ray will graze the surface of the water *AM.* If the source of light be still further removed from *C,* as to *l,* the ray will be reflected to *r* (§ 656). For all media there is an incident angle of this kind, called the critical or limiting angle, beyond which *total internal reflection* will take the place of refraction. The reflection is called total because all of the incident light is reflected, which is never the case in ordinary reflection. Hence, a surface at which total reflection takes place constitutes the most perfect mirror possible. The critical angle (with reference to air) is 48° 35′ for water; 40° 49′ for glass; 23° 43′ for diamond.

(*a.*) From this it follows, as may be seen by referring to Fig. 344, that to an eye placed under water, all visible objects above the water would appear within an angle of 97° 10′, or twice the critical angle for water.

(*b.*) The phenomena of total reflection may be produced by placing the bottle shown in Fig. 341 upon several books resting upon a table, and inverting the card so that a beam of light reflected obliquely upward from a mirror on the table may enter through the slit near the bottom of the bottle, taking a direction through the water similar to the line *lA* of Fig. 345. When one looks into an aquarium in a direction similar to *rA, images* of fish or turtles near the surface of the water are often seen.

(*c.*) Place a strip of printed paper in a test-tube; hold it obliquely in a tumbler of water and look downward at the printing which will be plainly visible. Change the tube gradually to a vertical position, and soon the part of the tube in the water takes a silvered appearance and the printing becomes invisible. Show that, in this case, the disappearance of the reading is due to total reflection. By dissolving a small bit of potassium dichromate in the water, the tube will have a golden instead of a silver-like appearance.

(*d.*) Fig. 346 represents a glass vessel partly filled with water. Mirrors are

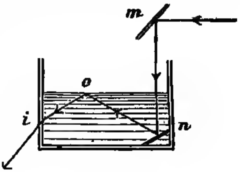


FIG. 346.

placed at *m* and *n*. In this way a ray may be reflected at *m*, *n* and *o*, and refracted at *i*.

(*e*.) Fig. 347 represents a glass jar with an opening, from which a stream of water issues under a head (§ 254 [*a*]) kept constant. Through a lens placed opposite this orifice, a concentrated beam of light from the heliostat is thrown into the stream of water as it issues. Internal reflection keeps most of it there, a prisoner. The stream of water is full of light and appears a stream of melted metal. Thrust a finger into the stream and notice the effect. Place a piece of red glass between the heliostat and the lens; the water looks like blood. Thrust the finger into the stream again. Repeat the experiment with pieces of glass of other colors in place of the red.

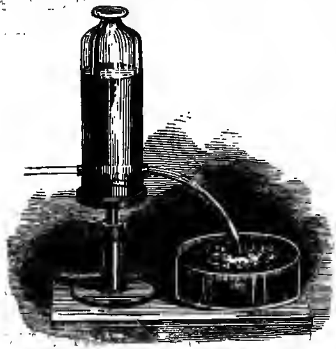


FIG. 347.

683. Refraction Explained.—To understand the way in which a ray of light is refracted, let us consider its passage through a glass prism, *ABC*. It must be understood that *the velocity of light is less in glass than in air, and that the direction in which a wave moves is perpendicular to its wave front.* A wave in the ether approaches the surface of the prism *AB*. When at *a*, the lower end of the wave front first strikes the glass and enters it. The progress of this end of the wave front, being slower than that of the other which is still in the air, is continually retarded until the whole front has entered the glass. The wave front thus assumes the position shown at *c*. But the path of the wave being perpendicular to the front of the wave, this

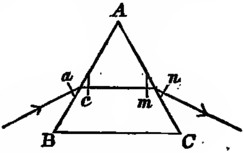


FIG. 348.

change of front causes a change in the direction of the ray which is thus *refracted toward* a perpendicular. The wave now moves forward in a straight line until the top of the wave front strikes *AC*, the surface of the prism, as shown at *m*. The upper end of the wave front emerging first into the air gains upon the other end of the front which is still moving more slowly in the glass. When the lower end emerges from the glass, the wave has the position shown at *n*. This second change of front involves another change in the direction of the ray which is now *refracted from* the perpendicular. (See *First Principles*, § 443, *a*.)

684. Three Kinds of Refractors.—When a ray of light passes through a refracting medium, three cases may arise:

(1.) When the refractor is bounded by planes, the refracting surfaces being parallel.

(2.) When the refractor is bounded by planes, the refracting surfaces being not parallel. The refractor is then called a prism.

(3.) When the refractor is bounded by two surfaces of which at least one is curved. The refractor is then called a lens.

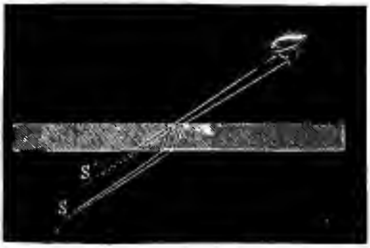


FIG. 349.

685. Parallel Plates.—When a ray passes through a medium bounded by parallel planes the refractions at the two surfaces are equal and contrary in direction. The direction of the ray after passing through the plate is parallel to its direction before entering; the ray merely suffers *lateral* aberration. Objects seen obliquely through such plates appear slightly displaced from their true position.

686. Prisms.—A prism produces two simultaneous effects upon light passing through it; a change of direction and decomposition. The second of these effects will be considered under the head of dispersion (§ 701).

(*a.*) Let *mno* represent a section formed by cutting a prism by a plane perpendicular to its edges. A ray of light from *L* being refracted at *a* and *b* enters the eye in the direction *bc*. The object being seen in the direction of the ray as it enters the eye (§ 659), appears to be at *r*. An object seen through a prism seems to be moved in the direction of the edge that separates the refracting surfaces. The rays themselves are bent toward the side that separates the refracting surfaces, or toward the thickest part of the prism.

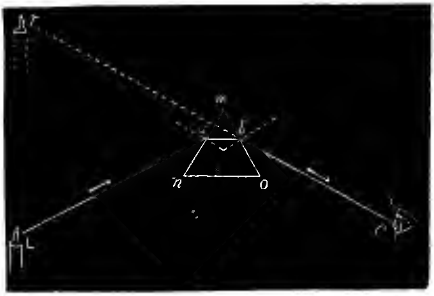


FIG. 350.

(*b.*) Prisms are generally made of glass, their principal sections being equilateral triangles. In order to give a liquid the form of a prism, it is placed in a vessel (Fig. 351) in which at least two sides are glass plates not parallel. Bottles are made for this purpose.

FIG. 351.

(*c.*) In Fig. 352, *ABC* is the principal section of a right-angled isosceles, glass prism, right-angled at *C*. A ray of light falling perpendicularly upon either of the cathetal (*cathetus*) surfaces, as *AC*, will not be refracted. With *AB*, it will make an angle of 45° which exceeds the critical angle for glass (§ 682). It will therefore be totally reflected and pass without refraction from the cathetal surface *BC*. Such prisms are often used in optics instead of mirrors.

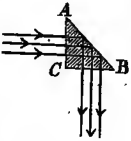


FIG. 352.

687. Lenses.—Lenses are generally made of crown glass which is free from lead, or of flint glass which contains lead and has greater refractive power. The curved surfaces are generally spherical. With respect to their shape, lenses are of six kinds:

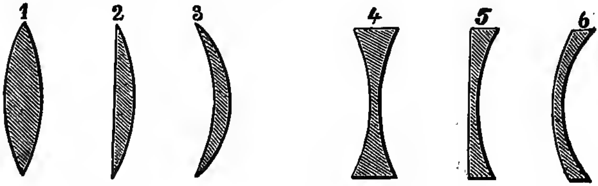


FIG. 353.

(1.) Double-convex,
(2.) Plano-convex,
(3.) Concavo-convex, or meniscus,
} Thicker at the middle than at the edges.

The double-convex may be taken as the type of these.

(4.) Double-concave,
(5.) Plano-concave,
(6.) Convex-concave, or diverging meniscus,
} Thinner at the middle than at the edges.

The double-concave may be taken as the type of these.

(*a.*) The effect of convex lenses may be considered as produced by two prisms with their bases in contact; that of concave lenses, by two prisms with their edges in contact.

688. Centre of Curvature; Principal Axis; Optical Centre.—A double-convex lens may be described as the part common to two spheres which intersect each other. The centres of these spheres are the centres of curvature of the lens. The straight line passing through the centres of curvature is the principal axis of the lens. In every lens there is a point on the principal axis called the optical centre. When the lens is bounded by spherical surfaces of equal curvature, as is generally the case, the optical centre is at equal distances from the two faces of the lens. Any straight line, other than the principal axis, passing through the optical centre is a secondary axis. (See *First Principles*, Fig. 216.)

(*a.*) If a ray of light passing through the optical centre be refracted at all, the two refractions will be equal and opposite in direction. The slight lateral aberration thus produced may be disregarded.

689. Principal Focus.—*All rays parallel to the principal axis will, after two refractions, converge at a point called the principal focus.* This point may lie on either side of the lens, according to the direction in which the light moves; it is a real focus. The greater the refracting power of the substance of which the lens is made, the nearer the principal focus will be to the lens. In a double-convex lens of crown glass, the principal focal distance is equal to the radius of curvature; in a plano-convex lens of the same material, it is twice as great.

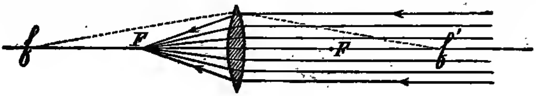


FIG. 354.

(*a.*) The position of the principal focus of a lens is easily determined. Hold the lens facing the sun. The parallel solar rays incident upon the lens will converge at the principal focus. Find this point by moving a sheet of paper back and forth behind the lens until the bright spot formed upon the paper is brightest and smallest. (See *First Principles*, Exp. 228.)

(*b.*) It is also true that rays diverging from a point at twice the principal focal distance from the lens will converge at a point just as far distant on the other side of the lens. Rays diverging from *f* will converge at *f'*, these two points being at twice the focal distance from the lens. By experimenting with a lens and candle-flame until the flame and its image are at equal distances from the lens, we are able, in a second way, to determine the principal focal distance of the lens. The conjugate foci situated at twice the principal focal distance are called *secondary foci.*

690. Conjugate Foci.—Rays diverging from a luminous point in the principal axis at a small distance beyond the principal focus on either side of the lens will form a focus on the principal axis beyond the other principal focus. Thus, rays from *L* will converge at *l*; conversely, rays from *l* will converge at *L* (§ 667). If the luminous point be in a secondary axis, the rays will converge to a point in the same secondary axis. *Two points thus related to each other are called conjugate foci; the line joining them always passes through the optical centre.*

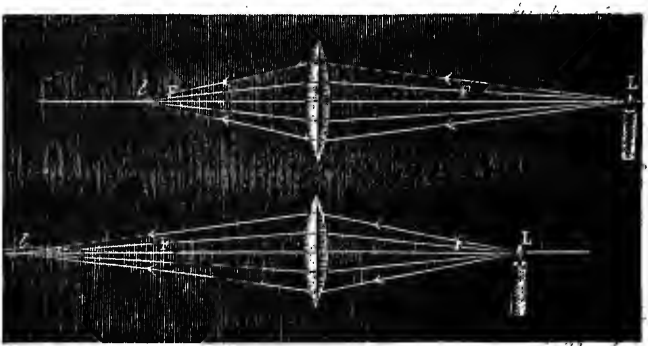


FIG. 355.

(*a.*) If the luminous point be more than twice the focal distance from the lens, the conjugate focus will lie on the other side of the lens at a distance greater than the focal distance, but less than twice the focal distance. If the luminous point be moved toward the lens, the focus will recede from the lens. When the luminous point is at one secondary focus, the rays will converge at the other secondary focus. When the luminous point is between the secondary and principal foci, the rays will converge beyond the secondary focus on the other side of the lens. When the luminous point is at the focal distance, the emergent rays will be parallel and no focus will be formed. When the luminous point is at less than the focal distance, the emergent rays will still diverge as if from a point on the same side of the lens, more distant than the principal focus.

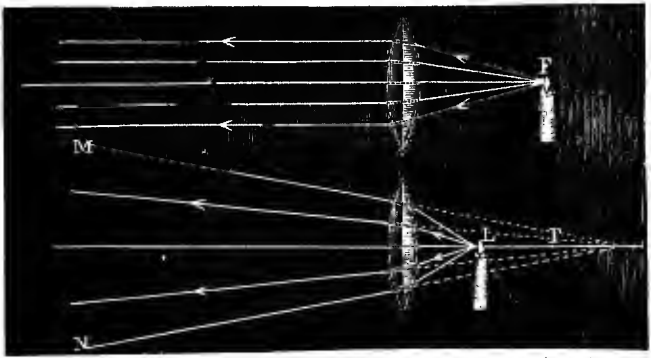


FIG. 356.

This focus will be virtual. Conversely, converging rays falling upon a convex lens will form a focus nearer the lens than the principal focus. (See Fig. 356.)

691. Conjugate Foci of Concave Lens.—Rays from a luminous point at any distance whatever will be made more divergent by passing through a concave lens.

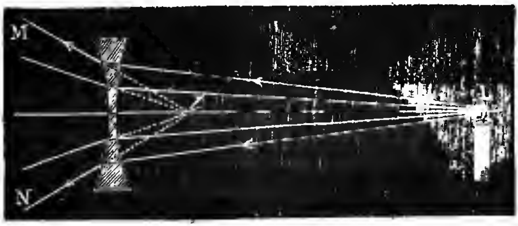


FIG. 357.

Rays parallel to the principal axis will diverge after refraction as if they proceeded from the principal focus. In any case, the focus will be virtual, and nearer the lens than the luminous point.

692. Images Formed by Convex Lenses.—The analogies between the convex lens and the concave mirror cannot have escaped the notice of the thoughtful pupil. Others will appear. If secondary axes be nearly parallel to the principal axis, well-defined foci may be formed upon them, as well as upon the principal axis. A number of these foci may determine the position of an image formed by a lens.

(*a.*) The linear dimensions of object and image are directly as their respective distances from the centre of the lens; they will be virtual or real, erect or inverted, according as they are on the same side of the lens or on opposite sides.

693. Construction for Real Images.—To determine the position of the image of the object *AB* (Fig. 358), draw from any point, as *A*, a line parallel to the principal axis. After refraction, the ray represented by this line will pass through *F*, the principal focus. Draw the secondary axis for the point *A*. The intersection of these two lines at *a* determines the position of the conjugate focus of *A*. In similar manner, the conjugate focus of *B* is found to be at *b*. Joining these points, the line *ab* is the image of the line *AB*.

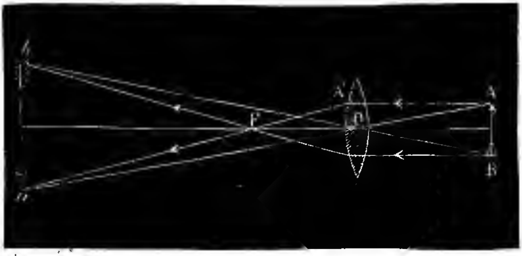


FIG. 358.

694. Diminished Real Image.—If the object be more than twice the focal distance from the convex lens, its image will be real, smaller than the object and inverted (Fig. 359). Construct the image as indicated in the last paragraph.

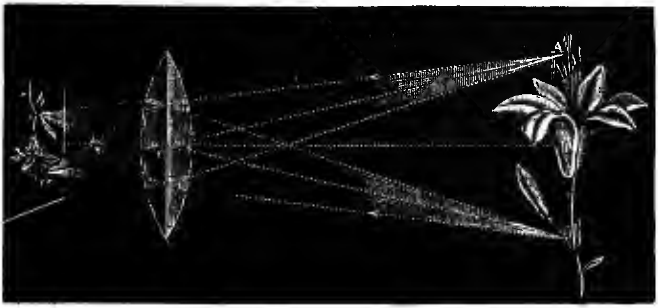


FIG. 359.

695. Magnified Real Image.—If the object be further from the lens than the principal focus, but at a distance less than twice the focal distance, the image will be real, magnified and inverted. (Fig. 360.) Construct the image.

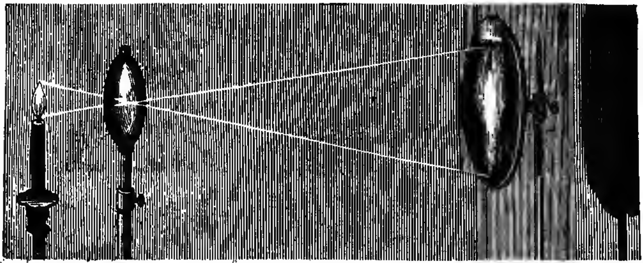


FIG. 360.

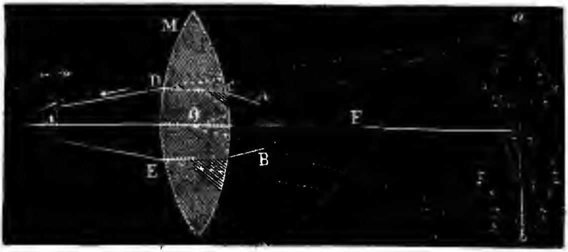


FIG. 361.

696. Virtual Image.—If the object be placed nearer the lens than the principal focus, the image will be virtual, magnified and erect. (Fig. 361.) This explains the familiar magnifying effects of convex lenses. Construct the image.

697. Image of Concave Lens.—Images formed by a concave lens are virtual, smaller than the object and erect. The construction of the image is shown in Fig. 362.

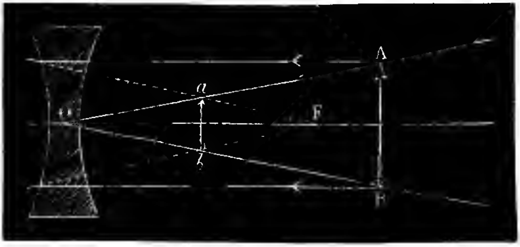


FIG. 362.

Note.—The power of the convex lens to form real and diminished images of distant objects and magnified images of near objects, is of frequent application in such optical instruments as the microscope, telescope, magic lantern, lighthouse lamps, etc. Owing to the identity between heat and luminous rays, a convex lens is also a "burning-glass."

698. Spherical Aberration.—The rays that pass through a spherical lens near its edge are more refracted than those that pass nearer the centre. They, therefore, converge nearer the lens. A spherical lens cannot refract *all* of the incident rays to the same point. Hence "spherical aberration" and its annoying consequences in the construction and use of optical apparatus.

EXERCISES.

1. (*a.*) What is refraction of light? (*b.*) State the laws governing the same, and (*c.*) give an illustrative diagram.

2. (*a.*) Name and illustrate by diagram the different classes of lenses. (*b.*) Explain, with diagram, the action of the burning-glass.

3. (*a.*) Explain the cause of total reflection. (*b.*) Show, with diagram, how the secondary axes of a lens mark the limits of the image.

4. (*a.*) Using a convex lens, what must be the position of an object in order that its image shall be real, magnified, and inverted? (*b.*) Same, using a concave lens?

5. (*a.*) Show how a ray of light may be bent at a right angle by a glass prism. (*b.*) The focal distance of a convex lens being 6 inches, determine the position of the conjugate focus of a point 12 inches from the lens. (*c.*) 18 inches from the lens.

6. (*a.*) The focal distance of a convex lens is 30 *cm.* Find the conjugate focus for a point 15 *cm.* from the lens. (*b.*) How may the focal length of a lens be determined experimentally?

7. If an object be placed at twice the focal distance of a convex lens, how will the length of the image compare with the length of the object?

8. A small object is 12 inches from a lens; the image is 24 inches from the lens and on the opposite side. Determine (by construction) the focal distance of the lens.

9. A candle flame is 6 feet from a wall; a lens is between the flame and the wall, 5 feet from the latter. A distinct image of the flame is formed upon the wall. (*a.*) In what other position may the lens be placed, that a distinct image may be formed upon the wall? (*b.*) How will the lengths of the images compare?

Recapitulation.—In this section we have considered the Definition, Index, Laws and Explanation of refraction; Internal Reflection; Plates, Prisms and Lenses; principal and conjugate Foci of lenses; Construction for conjugate foci and images; Spherical Aberration.

SECTION IV.

CHROMATICS.—SPECTRA.

699. Other Results of Refraction.—In our previous consideration of luminous rays we have studied the effect of reflection and refraction upon the *direction* of rays; in fact, we have dealt with only those properties which are common to all luminous rays. But the properties of light and the phenomena of refraction are not so simple as we might thus be led to suppose. Most luminous objects emit light of several kinds blended together. We must not be satisfied with our knowledge of light until we are able to sift these varieties one from the other, and to deal with any one kind by itself.

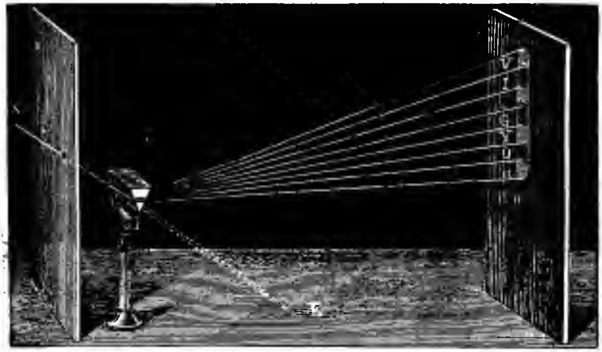


FIG. 363.

700. Solar Spectrum.—Admit a sunbeam through a very small opening in the shutter of a darkened room. The opening may be prepared by cutting a slit an inch (25 *mm.*) long and $\frac{1}{25}$ of an inch (1 *mm.*) wide in a card. See that the edges of the slit are smooth. Tack the card over an opening in the shutter. If we look at the aperture from *E* we shall see the sun beyond. The path of the beam from *S* to *E* is made visible by the floating dust. If a prism be placed in the path of the beam, as shown in Fig. 363, the sides of the slit and edges of the prism being horizontal, the beam will be refracted upward If the refracted beam be caught upon a screen, it will appear as a band of differently colored light, passing by imperceptible gradations from red at the bottom, through orange, yellow, green, blue and indigo to violet at the upper end of the beautifully colored band. *This colored band is called the solar spectrum.*

(*a.*) The different colors do not occupy equal space in the spectrum, orange having the least and violet the most. The initials of these colors form the meaningless word VIBGYOR, which may aid the memory in remembering these prismatic colors in their proper order. By placing the slit in a vertical position, and standing the prism on its end so that its edges will be parallel with the sides of the slit, the spectrum will be projected as a horizontal band.

701. Dispersion.—By looking at Fig. 363, it will be seen that the red rays have been refracted the least and the violet the most of all the luminous rays. *This separation of the differently colored rays by the prism is called the dispersion of light;* it depends upon the fact that rays of different colors are refracted in different degrees.

702. Pure Spectrum.—The spectrum above described is composed of overlapping and differently-colored images of the slit. In a pure spectrum these images must not overlap. The first requisite in preventing this overlapping is that the slit be very narrow.

(*a.*) The most simple way of producing a pure spectrum is to look through a prism at a very narrow slit in the shutter of a darkened room. The edges of the prism should be parallel to the slit; the prism should be at least five feet (1½ *m.*) from the slit; the prism should be turned until the colored image of the slit is at the least angular distance from the slit itself. A pure spectrum is also obtained by passing the beam through several prisms in succession, thus increasing the dispersion.

703. Fraunhofer's Lines.—A pure solar spectrum is not continuous, but is crossed by numerous dark lines, many hundreds of which have been counted and accurately mapped. The more conspicuous of these dark lines are distinguished by letters of the alphabet, as shown in Fig. 364. Each of these dark lines indicates that a particular kind of ray is wanting in solar light.

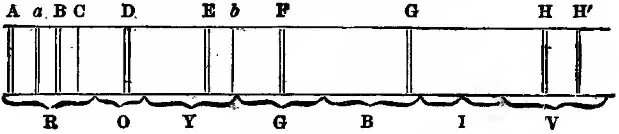


FIG. 364.

(*a.*) The spectra of incandescent solids are continuous, from the extreme red to a limit depending upon the temperature. The spectra of incandescent gases (not containing solid particles in suspension) are non-continuous, consisting of a number of definite bright lines. A candle or gas flame gives a continuous spectrum because it is chiefly due to the incandescence of solid carbon particles.

(*b.*) The spectroscope is an instrument for producing and observing pure spectra. It has proved to be one of the most powerful aids to modern science. It affords the most delicate means of chemical analysis; by its aid several elements have been discovered; the presence of $\frac{1}{2500000}$ of a grain of sodium has been detected by "spectrum analysis." It is of incalculable importance to the astronomer. For definite information, the pupil is necessarily referred to some of the excellent manuals upon the subject recently published.

Experiment 1.—Let the rays that have been dispersed by a prism fall upon a convex lens as shown in Fig. 365. *They will be refracted to a focus and recombined to form white light.* A concave mirror may be used to reflect the rays to a focus instead of using the lens as above described.

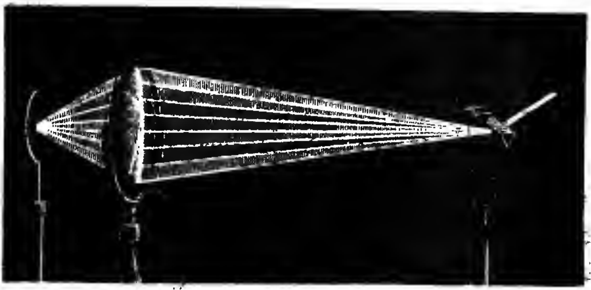


FIG. 365.

Experiment 2.—Make a "Newton's disc" of cardboard painted with the prismatic colors in proper proportion as indicated by Fig. 366. It is better to divide the surface given to each color into smaller sectors arranged alternately as shown in Fig. 367. You may paste sectors of properly colored paper upon the cardboard instead of painting them. Cause this disc to revolve rapidly by means of the whirling table or by fastening it to a large top. *Notice that the colors are blended and that the disc appears grayish white.*

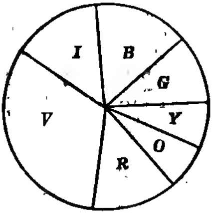


FIG. 366.

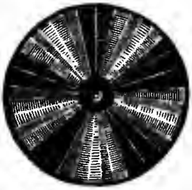


FIG. 367.

Experiment 3.—Hold a second prism near one that is used to produce a solar spectrum, the position of the second being inverted with reference to the first. If the dispersing prism be held as shown in Fig. 365, the second should be held with the refracting edge uppermost, the facing surfaces being parallel. The dispersed rays emerging from the first prism will pass through the second. *The rays separated by the first will be again blended by the second and appear as white light.*

Experiment 4.—Hold a hand mirror near the dispersing prism so as to reflect the refracted rays to a distant wall or ceiling. Give to the mirror a rapid, angular motion so that the spectrum is made to move to and fro very quickly in the direction of its length. *The spectrum changes to a band of white light with a colored spot at each end.* The effect is due to whst is known as the "Persistence of Vision," familiarly illustrated by the experiment of producing a ring of light by whirling a firebrand around a circle.

704. The Composition of White Light.—We have now shown, by both the processes of analysis and synthesis, that *white light is composed of the seven prismatic colors.* We have decomposed white light into its seven constituents and recombined these constituents into white light.

Experiment 5.—Paint three narrow strips of cardboard, one vermilion red, one emerald green and the other aniline violet. Be sure that the coats are thick enough thoroughly to hide the cardboard. When dry, hold the red strip in the red of the solar spectrum; it appears red. Move it slowly through the orange and yellow; it grows gradually darker. *In the green and colors beyond, it appears black.* Repeat the experiment with the other two strips and carefully notice the effects.

Experiment 6.—Make a loosely wound ball of candle wick; soak it in a strong solution of common salt in water; squeeze most of the brine out of the ball; place the ball in a plate and pour alcohol over it. Take it into a dark room and ignite it. Examine objects of different colors, as strips of ribbon or cloth, by this yellow light. *Only yellow objects will have their usual appearance.*

Experiment 7.—In a clear tumbler or large beaker glass of water, dissolve a little soap (white castile is desirable) or stir a few drops of an alcoholic solution of mastic. Hold the vessel in the hand and examine the liquid by transmitted sunlight. *Notice that it appears yellowish-red.* In a small test tube, either liquid will appear colorless. Place a black screen behind the vessel and examine the liquid by reflected sunlight. *Notice that it appears blue.*

705. Color of Bodies.—The color of a body is its property of reflecting or transmitting to the eye light of that particular color, the other rays being absorbed. This power may be described as selective absorption.

(*a.*) Properly speaking, color is not a property of matter, but of light. A ribbon is called red, but the redness belongs to the light, not to the ribbon. There would be more propriety in saying that the ribbon has *all the other colors* of the rainbow, because it absorbs the others and reflects the red. If the red ribbon be placed in the green or blue of the spectrum it will appear black because it receives no red rays to reflect. Colored substances decompose the incident light, absorbing some rays and assuming the hue of those they reflect or transmit to the eye. A body that absorbs very few of the rays is white; one that absorbs nearly all is black. Therefore, black is not a color but its absence.

(*b.*) If the rays that form the spectrum be divided into any two parts and the rays in each part be mixed, it is evident that each resultant color will contain what the other needs to make white light. Such are called *complementary colors*; either is said to be complementary to the other. The mixture of colors is a very different thing from the mixture of pigments.

(*c.*) Some bodies transmit one kind of rays and reflect another. Thus, gold leaf reflects yellow rays and transmits green rays. The beautiful blue of the summer sky, the terrible black of the storm cloud and the matchless sunset hues are effects due to the reflection, absorption, and transmission of sunlight by particles suspended in the atmosphere. An observer placed at a very high elevation, above most of the reflecting particles and looking into outer space, sees no blue canopy but only an inky darkness, illumined here and there by some gleaming planet or twinkling star.

706. The Rainbow.—The rainbow is due to refraction, reflection and dispersion of sunlight by water-drops. The necessary conditions are:

(1.) A shower during sunshine.

(2.) That the observer shall stand with his back to the sun, between the falling drops and the sun.

(*a.*) The centre of the circle of which the rainbow forms a part is in the prolongation of a line drawn from the sun through the eye of the observer. *This line is called the axis of the bow.*

707. Dispersion by a Raindrop.—Suppose the circle whose centre is at *C* (Fig. 368) to represent the section of a raindrop. A ray of sunlight, as *Sm,* falling upon the raindrop would be refracted at *m,* reflected at *n,* and again refracted at *m′*. In passing thus through the drop, the light is also decomposed. If *m′E* represent the path of a red ray, the violet ray will traverse a path above, because violet is refracted more than red. The path of this violet ray may be represented by *m′B*. If the raindrop be in the exact position for the red ray, *m′E,* to enter the eye of the observer, the violet and other colored rays will pass overhead and not be seen. This drop will appear red.

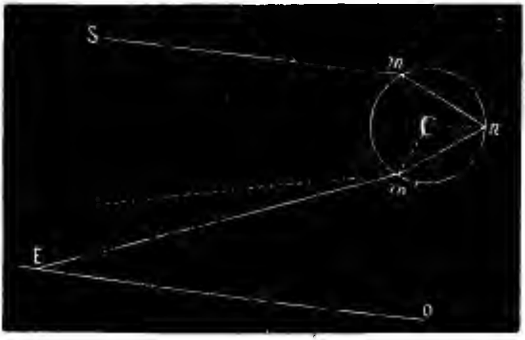


FIG. 368.

708. Successive Colors of the Rainbow.—In order that a violet ray may enter the eye at *E,* it must proceed from a drop situated *below* the one that sends the red ray. This drop will appear violet. Intervening drops will give the intervening colors of the solar spectrum in their proper order as is shown in Fig. 369. Owing to the distance of the sun, all of the incident rays are parallel with the axis, *EO,* drawn from the sun through *E,* the eye of the observer, to *O,* the centre of the circle of which the bow forms a part. The angle between the incident and the emergent ray, *SRE,* and consequently the angle, *REO*, is, for the red ray, about 42°. The angles *S' VE* and *VEO* are, for the violet ray, about 40°. The other colors lying between these, it will be seen that the angular width of the rainbow is about two degrees.

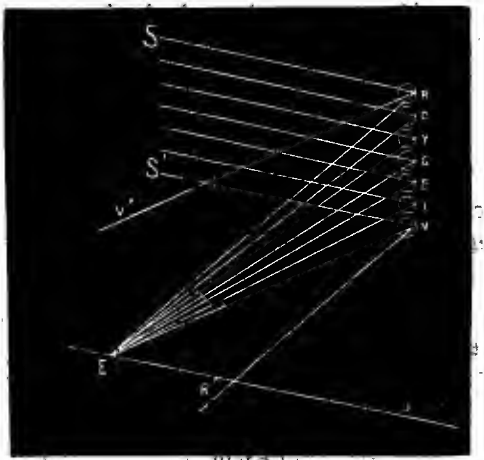


FIG. 369.

709. Form and Extent of the Rainbow.—

From Fig. 370, it will be seen that every drop in the arc of a circumference drawn, with *O* as a centre and with *O V* as radius, being opposite the sun and having the same angular distance from *OE*, viz., 40°, will send violet colored rays to the eye at *E*, and the violet colored part of the bow will be a circular arch. For the same reason, the red of the bow is a circular arch lying without the violet and at an angular distance of two degrees therefrom; the other colors will form circular

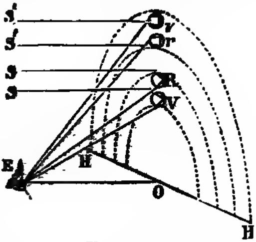


FIG. 370.

arches lying between these two. If the sun be at the horizon, *EO* will be horizontal and the arches will be semicircles. If the sun be above the horizon, *O* will be depressed below the horizon and less than semicircles will be seen. If the observer be on a mountain-top or up in a balloon, he may see more than a semicircle.

710. The Secondary Bow.—Sometimes two colored arches are seen, one within the other. The inner which we have just considered is called the primary bow; the outer, the secondary bow.

(*a.*) In explaining the primary bow, we traced a ray of light falling upon the top of the raindrop; to explain the secondary bow, we trace a ray falling upon its lower part. Such a ray, as *Sm*, will be refracted at *m*, reflected at *n* and *n'*, and again refracted at *m'*, coming to the eye at *E*. If the ray which thus comes to the eye at *E* be a red ray, the violet will follow *m' V*, and thus, passing below the eye because of its greater refrangibility, be lost to sight. The drop that sends a violet ray to the eye at *E* must be placed *above instead of below* the drop that sends the red ray. (Fig. 371.)

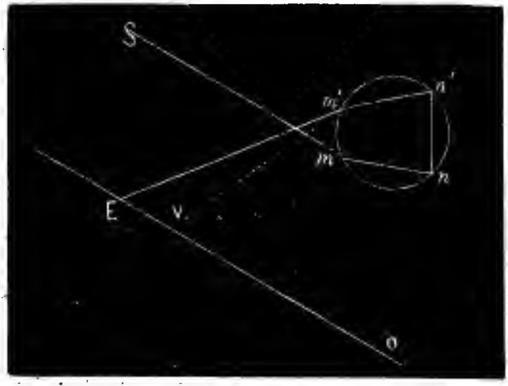


FIG. 371.

(*b.*) In the secondary bow, the red arch will be on the inside, with an angular distance from the axis, *EO*, of about 51°, while the violet will be on the outside at an angular distance of about 54°. In the case of either bow, some light is lost at each reflection; therefore, since there are more reflections in the secondary bow, this will appear fainter.

711. Chromatic Aberration.—It is impossible, by means of a single spherical convex lens, to bring all of the incident rays to a common focus. The blue and violet rays being refracted more than the red rays will converge at points nearer the lens. In consequence of this, when an image is projected upon a screen, the image is surrounded with a colored border, the color depending upon the distance of the screen from the lens. *This inability of a single lens to bring differently colored rays to the same focus is called chromatic aberration.*

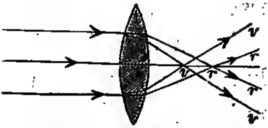


FIG. 372.

712. Achromatic Lens.—A convex lens of crown glass, by combination with a concave lens of flint glass, may have its dispersive power neutralized without completely neutralizing its refraction. As the converging effect of the compound lens is not destroyed, images may be formed; as the dispersive effect is destroyed, the colored fringe is avoided. *A combination of lenses by which dispersion is avoided and refraction secured is called an achromatic lens.*

Experiment 8.—In any convenient clamp, firmly press together two pieces of clean, thick, plate glass. A beautiful play of colors will be seen in the glass.

713. Interference of Light.—If a plano-convex lens of very small curvature be pressed down upon a flat plate of glass and looked at from above, colored rings (known as Newton's rings) may be seen around the centre of the lens. If the light be homogeneous (*i. e.*, composed of one kind of rays, as red) instead of white, the rings will be separated by dark spaces. The dark rings are due to the interference of the ether waves reflected from the lower surface of the lens and from the upper surface of the plate respectively. Whenever the distance between the two reflecting surfaces is such that the two sets of waves unite in opposite phases, a dark ring will appear. Two luminous waves, as well as two sound waves (§ 515), may unite so as to destroy each other. When white light is used, the color in any given ring is complementary to the color that is destroyed by interference. Similar colors are often seen in soap bubbles, in small quantities of oil that have been spread over large sheets of water, in mica, selinite and other crystals that easily cleave into thin plates, etc., and are due to the interference of light reflected from two surfaces very near each other.

Experiment 9.—Cover one side of a pane of glass with india ink, being sure that it is made opaque. Scratch 20 parallel lines about 2 *mm.* apart, upon the glass, so that the light may pass through. Standing about 6 or 7 meters from a lamp, with one eye shut and the other shaded from the sunlight, look through the lines ruled on the glass at the flame. Slowly moving the glass toward and from the eye, such a position may be found for it that many spectra of the flame may be seen separated by dark spaces.

Experiment 10.—Throw a sunbeam through a very small opening in the shutter of a darkened room. Receive the beam upon a convex lens of short focal length, placing a piece of red glass between the aperture and the lens. Place an opaque screen with a

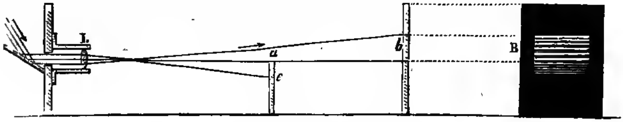


Fig. 373.

sharp edge beyond the focal distance of the lens, as at *e*, so as to cut off the lower part of the luminous cone and project the upper part thereof upon a screen at *b*. *A faint light is seen on the screen below the level of b and, therefore, within the geometrical shadow.* The part of the screen immediately above the level of *b* contains a series of dark and light bands as shown at *B*, which is a front view of the screen at *b*.

714. Diffraction.—The pupil may have noticed that when water waves strike a rock or other obstacle a little ways from the shore, part of the energy of the wave is expended in producing a second set of waves that seem to circle outward from the side of the obstacle as a centre. The original wave, which we may call the primary, passes directly onward while the other waves, which we may call secondary, wind around behind the obstacle. In similar manner, luminous waves are modified when they pass the edge of an opaque body, as in going through a narrow slit, in consequence of which the rays seem to be bent and to penetrate into the shadow. *Such an apparent bending of the luminous rays is called diffraction.* As the primary and secondary waves cut each other, they will unite at some points, crest with crest and, at other points, crest with trough. At the latter points, we shall have interference of light and the effects of colors produced thereby as explained above. The halos sometimes seen around the sun and moon are due to the diffraction of light by watery globules in the atmosphere. The colors often seen on looking through a feather or one's half-closed eyelashes at a distant source of brilliant light are also due to diffraction.

Experiment II.—Look carefully at the black and the white circles given in Fig. 374 and determine which *seems* to be the larger. Then carefully measure their diameters and *see which is the larger.*

715. Irradiation.—*A white or very bright object seen against a black ground appears larger than it really is; a black object on a white ground appears smaller than it really is. This effect is called irradiation.* It arises from the fact that the impression produced by a bright object on the retina extends beyond the outline of the image.

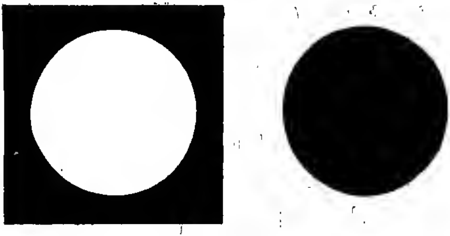


FIG. 374.

(*a*.) The effect of irradiation is very perceptible in the apparent magnitude of stars which are thus made to appear much larger than they otherwise would; also in the appearence of the new moon, the illuminated crescent seeming to extend beyond the darker portion, the new, thus, holding the old moon in its arms.

716. Properties of the Sunbeam.—We have seen that we may decompose a sunbeam by availing ourselves of the varying refrangibility of the different kinds of rays of which it is composed. We have been able in this manner to produce the seven prismatic colors from white light. But our analytic investigations must go still further. Beyond the limits of the *visible* spectrum, in both directions, there are rays that do not excite the optic nerve, the existence of which, however, may be easily proved. The sunbeam has three properties which we must consider in detail: luminous, thermal and actinic.

717. Luminous Rays.—The difference in color between the rays found in different parts of the spectrum is merely one of rate of vibration or wave-length. In respect to the visible spectrum, it may be said that color is to light what pitch is to sound. The length of an ether-wave that can awaken the sensation of redness is about $\frac{1}{39000}$ of an inch; of one that can awaken the sensation of violet, about $\frac{1}{57500}$. The waves corresponding to the intermediate colors have intermediate lengths. The visibility or invisibility of certain rays depends on the construction of the eye rather than on any peculiarity of the rays. It is quite possible that the eyes of some animals are so constructed that ultra-red rays may excite vision, and that the eyes of other animals are so constructed that ultra-violet rays may excite vision.

718. Thermal Rays.—If a very delicate thermometer or thermopile be successively placed in various parts of the spectrum it will be found that the temperature is scarcely affected in the violet, but that there is a continual increase in temperature as the thermometer is moved toward the other end of the spectrum, it being quite marked in the red and even beyond the red, wholly outside the visible spectrum. *We thus detect ultra-red rays constituting a heat spectrum.* Their position indicates their low refrangibility and increased wave-length. Because of its diathermancy, a rock-salt prism is desirable for this experiment; glass absorbs most of the ultra-red rays.

(*a.*) The oxy-hydrogen flame (Chemistry, § 41) develops little light but an intense heat. Most of its rays are obscure heat rays. If a small cylinder of lime be held in this flame, it emits a most brilliant light. This change of obscure heat rays into luminous rays is called *calorescence.*

719. Actinic Rays.—The actinic or chemical effects of sunlight are, in a general way, familiar to all. For example, plants absorb carbon from the atmosphere only during the day time. Silver chloride is very sensitive to this action of sunlight. The sensitive paper of the photographer will remain unchanged in the dark; it will be quickly blackened in the light. If a piece of paper freshly washed in a solution of sulphate of quinine, or some other fluorescent substance, be held in the ultra-violet rays, it will become visible. Such a slip of paper may be used as a test for the presence of actinic rays. By placing it successively in the different parts of the visible spectrum, it will be affected least in the red and most in the violet. Actinic effects will be found even beyond the violet, wholly outside the visible spectrum. *We thus detect ultra-violet rays constituting an actinic spectrum.* Their position indicates their high refrangibility; that their wave-length is less than that of the violet rays. A quartz prism is desirable for this experiment as glass quenches most of the actinic rays. The change of obscure, actinic rays into luminous rays is called *fluorescence.*

720. The Electric Light.—The electric light is particularly rich in these invisible rays. The dark heat rays may be sifted from the beam of light by passing it through a transparent solution of alum; only the luminous rays will be allowed to pass. The luminous rays may be sifted out by sending the beam through an opaque solution of iodine in carbon di-sulphide. If these solutions be placed in spherical flasks, they will constitute lenses that will refract the transmitted rays to well-defined foci. The focus of the transparent solution will be brilliantly illuminated, but will have little heating power; that of the opaque solution will be invisible, while gun-cotton placed there may be instantly exploded. Platinum-foil has been raised to a red heat at one of these dark foci. Photographs are now frequently taken by the electric light.

721. Selective Radiation and Absorption.—Radiation of light or heat consists in giving motion to the ether; absorption consists in taking motion from the ether. Molecules of one kind are able to vibrate at one rate; those of another kind may be obliged to vibrate at a different rate. The first set of molecules may be able to give to the ether, or take from it, a rate of vibration which, in the ether, constitutes obscure heat. These molecules can absorb or radiate obscure heat. They may be unable to vibrate at the higher rate which will enable them to absorb or radiate light. They must either transmit or reflect light that falls upon them. In other words, a body absorbs with special energy the kind of rays itself can radiate, both the absorption and the radiation depending upon the possible rate of vibration of the molecules of the body.

(*a.*) In the case of gases, the period of molecular vibration is sharply defined. Gaseous molecules, like musical strings, can vibrate at only definite rates. Liquid and solid molecules, like sounding-boards, are able to vibrate at different rates lying between certain fixed limits. These limits depend largely upon the temperature. This principle underlies solar, spectrum analysis.

722. Relation between Radiation and Absorption.—Transparent bodies *are* transparent because the ether-waves which produce or constitute light pass between the molecules of such bodies without having their wave-motion transferred to the molecules. Diathermanous bodies transmit heat freely because the ether-waves which produce or constitute heat pass between the molecules of such bodies without having their peculiar wave-motion transferred to the molecules of the body through which they pass. When a ray of light or heat, in passing through a substance, gives its energy to the molecules between which it is passing in the ether, the ray is absorbed. It no longer exists as radiant energy; it has become absorbed heat and warms the body. It is no longer a motion of the ether; it has become a motion of ordinary matter. As in the case of radiant heat, so with light; the best absorbents are the best radiators. A piece of transparent, colorless glass will absorb very little light; heat it intensely and it will radiate very little light. On the other hand, a piece of opaque glass will absorb a great deal of light; when heated intensely, it will radiate a great deal of light.

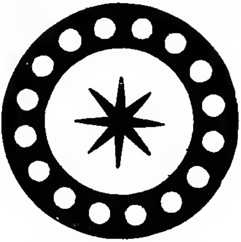


FIG. 375.

(*a.*) If an intensely heated pot of melted lead, tin or plumber's solder be carried into a dark place and the dross skimmed aside by a red-hot iron ladle, the liquid metal (which in sunlight would reflect rather than absorb the light) will appear less bright than the surrounding dross. If a piece of platinum-foil bearing an ink-mark be heated to incandescence and viewed in a dark room, the ink-mark will radiate more light than the metal. Exposed to sunlight, the ink-mark will absorb more light than the metal. If a chalk-mark be made on a black poker, the poker heated red-hot

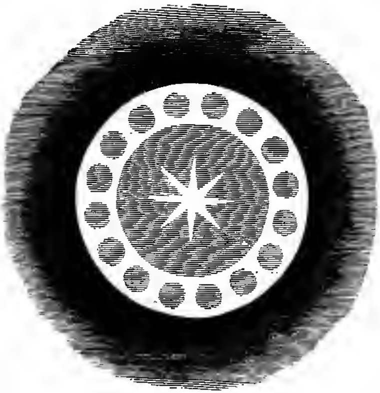


FIG. 376.

and viewed in a dark room, the chalk will be less luminous than the iron. If a piece of stone-ware of black and white pattern (Fig. 375) be heated to redness and viewed in a dark room, the black will shine more brightly than the white, the pattern being reversed as shown in Fig. 376.

EXERCISES.

1. Give the best reason you can think of, why the rainbow is a circular arc and not a straight line or of some other shape.

2. Taking the velocity of light to be 188,000 miles per second and the wave-length for green light to be .00002 of an inch, how many waves per second beat upon the retina of an eye exposed to green light?

3. How may spherical and chromatic aberration caused by a lens be corrected?

4. Describe Fraunhofer's lines and tell how they may be produced. Why not through a circular orifice?

5. Describe in full what is meant by dispersion and the dispersive power of a medium.

Recapitulation.—To be amplified by the pupil for review.

CHROMATICS, ETC.

- **COMPLEXITY OF SUNBEAM.....**
  - ANALYSIS..
    - DISPERSION.
      - *By Prisms.*
      - *By Water Drops.*
    - SPECTRA....
      - *Solar.*
      - *Luminous.*
      - *Thermal.*
      - *Actinic.*
  - SYNTHESIS.
    - BY LENSES.
    - BY MIRRORS.
    - BY PRISMS.
    - BY PERSISTENCE OF VISION.
- **COLORS.........**
  - CAUSE OF.
  - COMPLEMENTARY.
  - SKY.

INTERFERENCE.

DIFFRACTION.

IRRADIATION.

RADIATION AND ABSORPTION RELATED.

SECTION V.

OPTICAL INSTRUMENTS.—POLARIZATION.

723. Photographers' Camera.—The photographer's camera is nearly the same as the camera-obscura described in § 650. Instead of the darkened room we have a darkened box, *DE*; instead of the simple hole in the shutter, we have an achromatic convex lens, placed in a sliding tube at *A*.

(*a.*) Sometimes, one part of the box slides within the other part with a movement like that of a telescope tube. Sometimes the front and the back of the box are joined by flexible sides, as shown in Fig. 377, so that the distance between *A* and *E* may be varied. A ground-glass plate is placed in the frame at *E*, which is adjusted so that a well-defined, inverted image of the object in front of *A* is projected upon the glass plate. (See § 694.) This adjustment, or "focussing," is completed by moving the lens and its tube by the toothed wheel at *D*. When the "focussing" is satisfactory, *A* is covered with a black cloth, the ground-glass plate replaced by a chemically-prepared sensitive plate, the cloth removed and the image projected thereon. The light works certain chemical changes where it falls upon this plate and thus a more lasting image is produced. The preliminary and subsequent processes necessarily involved in photography cannot be considered here; they belong rather to chemistry.

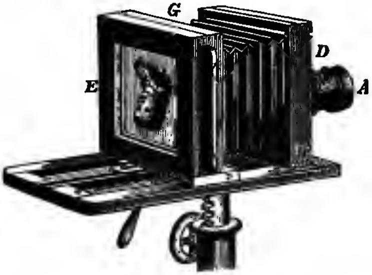


FIG. 377.

724. The Human Eye.—This most admirable of all optical instruments is a nearly spherical ball, capable of being turned considerably in its socket. The outer coat, *S*, is firm and, excepting in front, is opaque. It is called the "white of the eye," or the sclerotic coat. Its transparent part in front, *C*, is called the *cornea*. The cornea is more convex than the rest of the eyeball. The cornea fits into the coat, *S*, as a watch crystal does into its case. Behind the cornea, is a curtain, *I*, called the *iris*. It is colored and opaque; the circular window in its centre is called the *pupil*. The color of the iris constitutes the color of the eye. Back of the pupil is the *crystalline lens*, *L*, built of concentric shells of varying density. Its shape is shown in the figure. This lens divides the eye into two chambers, the anterior chamber containing a limpid liquid called the *aqueous humor*; the posterior chamber containing a transparent jelly, *V*, called the *vitreous humor*. The viteous humor is enclosed in a transparent sack, *H*, called the *hyaloid membrane*. The cornea, aqueous humor, crystalline lens and vitreous humor are refracting media. Back of the hyaloid membrane is the *retina*, *R*, an expansion of the optic nerve. At the centre of the back of the eye is a slight depression called the *yellow spot*. This is the most sensitive part of the retina. The point at which the optic nerve enters the eye is called the *blind spot*. It is at one side of the yellow spot, nearer the nose. Between the retina and the sclerotic coat is *N*, the *choroid coat*, intensely black and opaque.

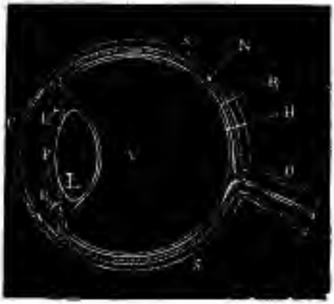


FIG. 378.

The eye, optically considered, is simply an arrangement for projecting inverted real images of visible objects upon a screen made of nerve filaments. The image thus formed is the origin of the sensation of vision. (§ 650 *c.*)

Experiment 1.—Stick two needles into a book-cover or board about 6 inches apart. Close one eye and hold the book so that the needles shall be nearly in range with the open eye and about 6 and 12 inches respectively from it. One needle will be seen distinctly while the image of the other will be blurred. Fix the view definitely on the needle that appears blurred and it will become distinct, but *you cannot see both clearly at the same time.* (See Fig. 354.)

Experiment 2.—Close the left eye, look steadily at the cross below, holding the book about a foot from the face. The dot is plainly visible as well as the cross. Keep the eye fixed on the cross and move the book slowly towards the face. When the image of the dot falls on the blind spot of the eye, the dot will disappear. Hold the book in this position for a moment and see if the changing convexity of the crystalline lens throws the image of the dot off the blind spot, making the dot again visible.

✠ ●

Experiment 3.—Stick a bright red wafer upon a piece of white paper. Hold the paper in a bright light and look steadily at the wafer, for some time, with one eye. Turn the eye quickly to another part of the paper or to a white wall and a greenish spot, the size and shape of the wafer, will appear. The greenish color of the image is complementary to the red of the wafer. If the wafer be green, the image afterward seen will be of a reddish (complementary) color.

725. The Action of the Eye.—The iris acts as a self-regulating diaphragm, dilating the pupil and thus admitting more light when the illumination is weak; contracting the pupil and cutting off more light when the illumination is strong. *The adjustment for distance* (necessary to throw the foci on the retina) is effected by changing the convexity of the anterior surface of the crystalline lens. (See Experiment 2.) The impression upon the retina does not disappear instantly when the action of the light ceases but continues for about an eighth of a second. The result is what is called the *persistence of vision.* If the impressions are repeated within the interval of the persistence of vision, they appear continuous. (Compare § 490.) This phenomenon is well illustrated by the luminous ring produced by swinging a firebrand around a circle and in the action of the common toy known as the thaumatrope or the zoetrope. The sensibility of the retina is easily exhausted, as though the terminal cones of the optic nerve became tired of vibrating at a given rate and thus became insensible to certain impulses of light corresponding to a certain color. (See Experiment 3.) The retinas of some eyes seem to be affected similarly by rays of different colors. The owners of such eyes are said to be color blind. Serious railway accidents caused by mistaking the color of signal lights, have led to examinations for *color blindness.* Such examinations have shown that this optical defect is much more common than is generally supposed, many persons being color blind without knowing it.

726. Estimates of Size and Distance.—We estimate the size of visible objects (by instinct or by experience) from the visual angle and the supposed distance of the object and by comparison with objects of known size. If we are mistaken in the distance of the object, we are often mistaken in our estimate of its size. We estimate the distance of an object by the distinctness with which we see it, by comparison with objects of known distance and by the muscular effort we make in turning the eyes inward so as to direct them upon the object. The axes of the eyes intersect at the object. The angle between the axes is called the *optical angle.* The greater the optical angle, the less the distance.

(*a.*) The more obscure an object, the more distant (and, consequently, the larger) it seems to be. Hence, the apparent enormous size of objects seen in a fog. When the moon appears on the horizon, we see that she is beyond all terrestrial objects in that direction and she seems farther off (and, consequently, larger) than when she is overhead, there being then no intervening objects for comparison. But the moon is actually nearer us when she is in the zenith than when in the horizon and the visual angle is, consequently, greater.

727. Distinct Vision.—*That vision may be distinct, the image formed on the retina must be clearly defined, well illuminated and of sufficient size.*

(*a.*) The power of the eye to adjust itself for distance is limited. When a book is held close to the eyes, the rays from the letters are so divergent that the eye cannot focus them upon the retina. The near point of vision is generally about 3½ inches from the eye. As parallel rays are generally brought to a focus on the retina when the eye is at rest, the far point for good eyes is infinitely distant. Owing to the small size of the pupil, rays from a point 20 inches or more distant are practically parallel.

(*b.*) The near point of some eyes is less than 3½ inches, while the far point is only 8 or 10 inches. The owners of such eyes are *near-sighted.* In such eyes, the retina is too far back, the eyeball being elongated in the direction of its axis. The remedy is in concave glasses.

(*c.*) The near point of some eyes is about 12 inches and the far point is infinitely distant. The owners of such eyes are *far-sighted.* In such eyes the retina is too far forward, the eyeball being flattened in the direction of its axis. The remedy is in convex glasses.

(*d.*) The eye loses its power of adjustment with age, the crystalline lens losing its elasticity. The cause of the difficulty is different from that of far-sightedness, but the remedy is the same.

728. Magnifying Glasses.—A magnifying glass, or simple microscope, is a convex lens, generally double-convex. The object is placed between the lens and its principal focus. The image is virtual, erect and magnified (Fig. 361.) The visual angle subtended by the image is greater than that subtended by the object.

729. Compound Microscope.—The compound microscope consists of two or more convex lenses placed in a tube. One of these, *o*, called the object glass or objective, is of short focus. The object, *ab*, being placed slightly beyond the principal focus, a real image, *cd*, magnified and inverted, is formed within the tube (§ 695). The other lens, *E*, called the eyeglass, is so placed that the image formed by the objective lies between the eyeglass and its focus. A magnified virtual image, *AB*, of the real image is formed by the eyeglass (§ 696) and seen by the observer. (See Fig. 379.)

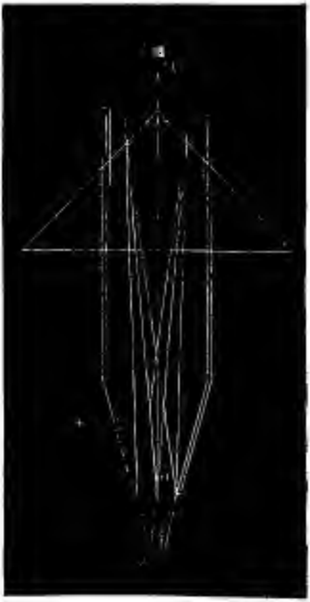


FIG. 379.

(*a.*) Compound microscopes are usually provided with several objectives of different focal distances, so that a selection may be made according to the magnifying power required. The powers generally used range from 50 to 350 diameters (*i. e.*, they multiply linear dimensions so many times). The object generally needs to be intensely illuminated by a concave mirror or convex lens.

730. Galilean Telescope; Opera Glass.—In the telescope attributed to Galileo, the objective is a double convex and the eye-piece is a double concave lens. The concave lens intercepts the rays before they have reached the focus of the objective; were it not for this eye-piece, a real, inverted image would be formed back of the position of the concave lens. The rays from *A*, converging after refraction by *O*, are rendered diverging by *C*; they seem to diverge from *a*. In like manner, the image of *B* is formed at *b*. The image, *ab*, is erect and very near. An opera-glass consists of two Galilean telescopes placed side by side. In a good instrument, both lenses are achromatic.

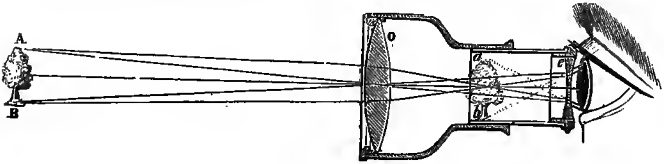


FIG. 380.

731. Astronomical Telescope; Refractor.—Astronomical telescopes are of two kinds—refractors and reflectors. Fig. 381 represents the arrangement of the lenses and the direction of the rays in the refracting telescope. The object-glass is of large diameter that it may collect many rays for the better illumination of the image. The inverted, real image formed by the objective,

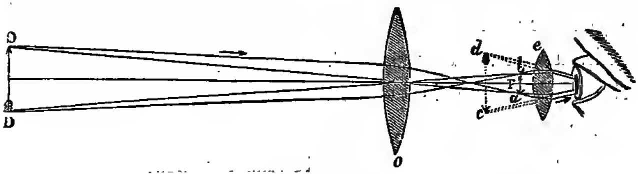


FIG. 381.

O, is magnified by the eye-piece, as in the case of the compound microscope. The visible image, *cd*, is a virtual image of *ab*, the real image of *AB*.

(*a*.) The telescope now building for the Lick Observatory (on the summit of Mt. Hamilton, California, 4,400 ft. above the level of the sea) will be the largest refractor in the world. The objective is $38\frac{1}{4}$ inches in diameter. The telescope will be 60 ft. in length. The two glasses will cost $51,000; the mounting will cost as much more; the dome of the Observatory will cost $50,000.

732. Reflecting Telescopes.—A reflecting telescope consists of a tube closed at one end by a concave mirror, so placed that the image thus formed may be magnified by a convex lens used as an eye-piece. Sometimes the eye-piece consists of a series of convex lenses placed in a horizontal tube, as shown in Fig. 382. The rays from the mirror may be reflected by a cathetal prism, *mn* (§ 686 [*c*]), and a real image formed at *ab*. This image is magnified by the glasses of the eye-piece and a virtual image formed at *cd*. The Earl of Rosse built a telescope with a mirror six feet in diameter and having a focal distance of fifty-four feet. (Appendix T.)

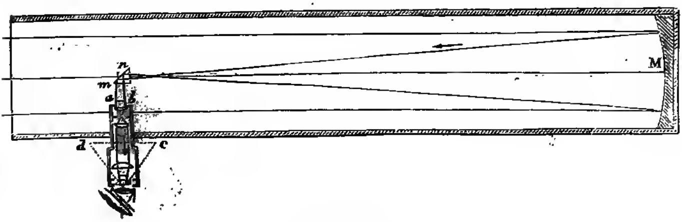


FIG. 382.

733. Terrestrial Telescope.—The inversion of the image in an astronomical telescope is inconvenient when viewing terrestrial objects. This inconvenience is obviated in the terrestrial telescope by the interposition of two double convex lenses, *m* and *n*, between the objective and the eye-piece. The rays, diverging from the inverted image at *I*, cross between *m* and *n* and form an erect, magnified, virtual image at *ab*.

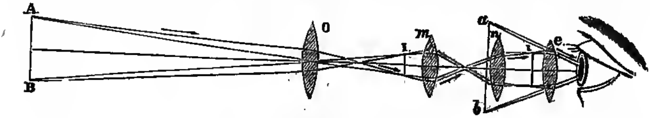


FIG. 383.

Experiment 4.—Reflect a horizontal beam of sunlight into a darkened room. In its path, place a piece of smoked glass on which you have traced the representation of an arrow, *AB* (Fig. 384), or written your autograph. Be sure that every stroke of the pencil has cut through the lamp black and exposed the glass beneath. Place a convex lens beyond the pane of glass, as at *L*, so that rays that pass through the transparent tracings may be refracted by it as shown in the figure. It is evident that an image will be formed at the foci of the lens. If a screen, *SS*, be held at the positions of these foci, *a* and *b*, the image will appear clearly cut and bright. If the screen be held nearer the lens or further from it, as at *S′* or *S″*, the picture will be blurred.

FIG. 384.

734. Magic Lantern.—In the magic lantern, a lamp is placed at the common focus of a convex lens in front of it and of a concave mirror behind it. The light is thus concentrated upon *ab*, a transparent picture, called the "slide." A system of lenses, *m*, is placed at a little more than its focal distance beyond the slide. A real, inverted, magnified image of the picture is thus projected upon the screen, *S*. The tube carrying *m* is adjustable, so that the foci may be made to fall upon the screen and thus render the image distinct. By inverting the slide, the image is seen right side up. The solar and electric microscopes act in nearly the same way, the chief difference being in the source of light.

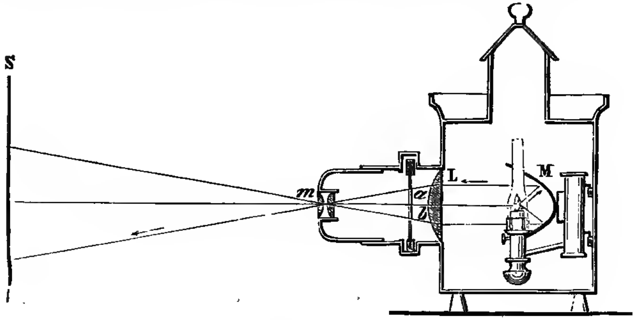


FIG. 385.

(*a*.) Directions for making a simple magic lantern may be found on page 84 of Mayer and Barnard's little book on *Light*. Fig. 386 represents a very compact and efficient lantern, known as Marcy's Sciopticon, and furnished by James W. Queen & Co. of Philadelphia.

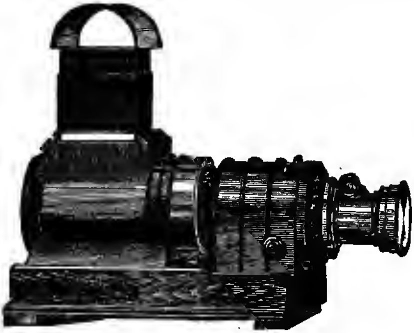


FIG. 386.

735. Stereoscopic Pictures.—Close the left eye and hold the right hand so that the forefinger shall hide the other three fingers. Without changing the position of the hand, open the left and close the right eye. The hidden fingers become visible in part. Place a die on the table directly in front of you. Looking at it with only the left eye, three faces are visible, as shown at *A*, Fig. 387. Looking at it with only the right eye, it appears as shown at *B*. From this we see that *when we look at a solid, the images upon the retinas of the two eyes are different.* If, in any way, we combine two drawings, so as to produce images upon the retinas of the two eyes like those produced by the solid object, we obtain the idea of solidity.

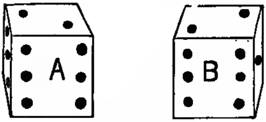


FIG. 387.

736. The Stereoscope.—To blend these two pictures is the office of the stereoscope. Its action will be readily understood from Fig. 388. The diaphragm, *D*, prevents either eye from seeing both pictures at the same time. Rays of light from *B* are refracted by the half-lens *E'* so that they seem to come from *C*. In the same way, rays from *A* are refracted by *E* so that they also seem to come from *C*. The two slightly different pictures thus seeming to be in the same place at the same time are successfully blended; the picture "stands out," or has the appearance of solidity. If the two pictures of a stereoscopic view were exactly alike, this impression of solidity would not be produced.

FIG. 388.

737. Polarization.—If a horizontal string, tightly drawn, be hit a vertical blow, a wave will be formed with vibrations in a vertical plane. If the string be hit a horizontal blow, a wave will be formed with vibrations in a horizontal plane. Thus a transversal wave is capable of assuming a particular side or direction while a longitudinal wave is not. This is expressed by saying that a transversal wave is capable of polarization. Polarization of light may be produced in three ways—by absorption, by reflection and by double refraction.

(*a.*) Polarized light presents, to the naked eye, the same appearance as common light. In polarization experiments, two pieces of apparatus must generally be employed; one to produce polarization; the other to show it. The former is called the *polarizer*; the latter, the *analyzer*. Apparatus that serves for either of these purposes will also serve for the other.

738. Planes of Vibration in Sunbeam.—If we imagine a sunbeam to be cut by a plane perpendicular to the direction of the beam, we may suppose the section to consist of vibrations moving in every possible plane, as represented by Fig. 389. It is not to be supposed that all of these planes will intersect at the same point. There will be many rays whose planes of vibration are vertical, many whose planes of vibration are horizontal, etc.

FIG. 389.

FIG. 390.

739. Polarization by Absorption.—If a sunbeam fall upon a substance whose molecular structure allows vibrations in only a particular plane, say vertical, the substance may be compared to a frame with vertical bars, as represented by Fig. 390.

Such a frame or such a substance will absorb the rays whose vibrations lie in a plane that is horizontal or nearly so, convert them into absorbed heat and transmit, as polarized light, those rays whose vibrations lie in a plane that is vertical or nearly so. A plate cut in a certain way from a crystal of tourmaline acts in such a way; it is called a tourmaline analyzer. If the sunbeam fall upon a substance that allows vibrations in only a horizontal plane, the substance may be compared to a frame with horizontal bars, as represented in Fig. 391. Such a body will quench all the rays whose vibrations lie in a plane that is vertical or nearly so and transmit, as polarized light, those rays whose vibrations lie in a plane that is horizontal or nearly so. The tourmaline analyzer previously used acts in this way when turned a quarter way around.

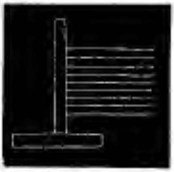


FIG. 391.

740. Tourmaline Tongs.—If these two frames, or two tourmaline analyzers, be placed one over the other in such a way that the bars of the second shall be perpendicular to those of the first, it will be seen that the first will quench or absorb part of the rays, while the rays transmitted by the first as polarized light will be quenched by the second. But if the bars of the second be parallel to those of the first, the polarized light transmitted by the first will also be transmitted by the second. This partial or total absorption of luminous rays is shown easily with the "tourmaline tongs," which consist of two tourmaline

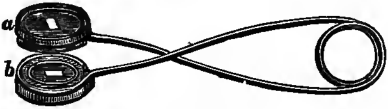


FIG. 392.

plates set in movable discs (Fig. 392). Light transmitted by either plate is polarized (and colored by the accidental tint of the tourmaline). When the plates are superposed, polarized light may be transmitted by both, or all of the incident light may be absorbed according to their relative positions as above stated.

741. Polarization by Reflection.—Light is polarized when the rays whose vibrations lie in a particular plane are alone allowed to pass. This effect may be produced by causing a beam of light to be reflected by a non-metallic mirror at a certain angle which depends upon the nature of the reflecting substance. For glass, the ray must make with the reflecting surface an angle of 35° 25′ (angle of incidence = 54° 35′).


FIG. 393.

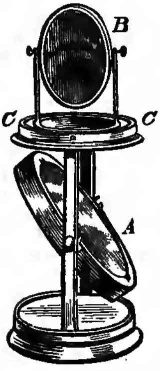


FIG. 394.

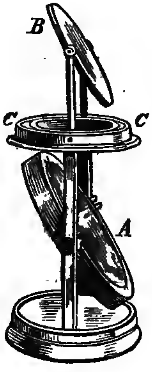


FIG. 395.

742. Malus's Polariscope.—This instrument has two reflectors made of bundles of glass plates. (An ordinary looking-glass is a metallic mirror.) Of these, *A* is called the polarizer and *B* the analyzer. Both reflectors turn upon horizontal axes; *B* also turns upon a vertical axis by means of the horizontal circles, *CC*.

When *A* and *B* are placed at the polarizing angle with the vertical axis, a beam of light is made to fall upon the polarizer in such a direction that the reflected light will pass vertically upward to *B*. This reflected light will be polarized. The polarized light will be reflected by *B* when the second reflector is parallel to the first (Fig. 395); it will be absorbed or transmitted when *B* is perpendicular to *A* (Fig. 394).

(*a*.) Place *B* as shown in Fig. 395. Throw a beam of light upon *A*, the room being darkened. The light reflected from *B* will form a white spot upon the side of the room. Turn the collar, *C*, slowly around. The spot of light will move around the sides of the room, gradually growing fainter. When *C* has been turned a quarter way around (Fig. 394), the spot has wholly disappeared. Beyond this it grows brighter until *C* has been turned half way around, when it is as bright as at the beginning. When *C* has been turned three-quarters around, the spot again disappears, again reappearing as *C* and *B* are brought to their original positions.

743. Double Refraction.—A crystal of Iceland spar shows a very important effect upon an incident beam. The retardation of the vibrations whose plane is parallel to the axis (the line joining the two obtuse angles of the crystal) is different from the retardation of the vibrations whose plane is perpendicular to the axis. This difference in change of velocity produces a difference in the refraction of the two sets of rays. A beam of light,

FIG. 396.

therefore, falling upon a crystal of Iceland spar will be generally split into two, producing the effect known as double refraction.

(*a.*) A small object, as a dot or line, viewed through a crystal of Iceland spar, will generally show two images formed by light oppositely polarized. If the eye be placed directly above the dot and the crystal be slowly turned around, one image known as the ordinary image will remain stationary, while the other known as the extraordinary image will revolve about it at a varying distance. The ordinary ray has a constant and the extraordinary ray a variable index of refraction.

(*b.*) On looking, through a tourmaline or any other analyzer, at the two images formed by double refraction, it will be found that there is a marked difference in the brightness of the two images. As the analyzer is turned around, one image grows brighter and the other fainter, the greatest brightness of one being simultaneous with the extinction of the other.

744. Nicol's Prism.—One of the most valuable pieces of polarizing apparatus is Nicol's prism. A crystal of Iceland spar is bisected in a plane, *AB*, passing through its two obtuse angles, as shown in the figure. The two halves are then cemented in their original position with Canada balsam. The refractive power of the balsam is such that the extraordinary ray passes through it at *E*, while the ordinary ray, striking the balsam at an angle greater than its critical angle, is reflected at *N*, passes out

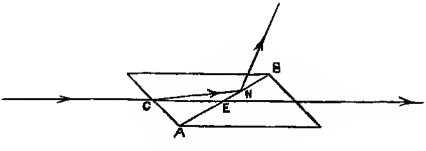


FIG. 397.

of the crystal and is then absorbed by the surrounding frame of the prism. Since the "Nicol" allows only the extraordinary ray to pass, it may be used, like a tourmaline, as an analyzer or as a polarizer.

(*a.*) When the light of the blue sky is looked at through a Nicol or other analyzer (at an angular distance of 90° from the sun), a difference of brightness is seen as the analyzer is turned. The degree of difference between the maximum and the minimum of light thus observed measures the degree in which such light is polarized.

745. A Simple Polariscope.—In the accompanying figure, *B* is a pile of six or eight glass plates about 15 *cm.* square, serving as a polarizer. A Nicol at *E* serves as an analyzer. The Nicol is supported, as shown in the figure, so as to view the centre of the polarizer at the polarizing angle of glass. The prism should be mounted so that it may be turned on its axis in its support. *G* is a piece of ground glass for cutting off the images of outside objects. The object to be examined is placed on the glass table or shelf, *T*. The instrument is placed with *G* facing a window and covered with a cloth to cut off unpolarized light.

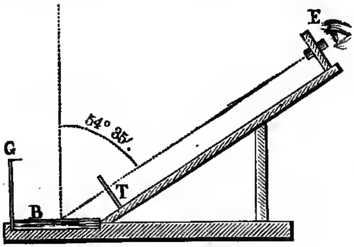


FIG. 398.

(*a.*) Place a thin plate (film) of mica or selenite on the table, *T*, and look through the Nicol while you turn it about on its axis. A beautiful display of colors is seen, each reaching its maximum brilliancy, fading away and changing to its complementary color as the analyzer is turned. The colors and changes of color are due to the interference of polarized rays.

Recapitulation.—To be amplified by the pupil for review.

- OPTICAL INSTRUMENTS, ETC.
  - **CAMERA**
    - OBSCURA.
    - PHOTOGRAPHER'S.
  - **HUMAN EYE AND ITS ACTION.**
  - **MICROSCOPES**
    - SIMPLE.
    - COMPOUND.
  - **TELESCOPES**
    - REFLECTORS.
    - REFRACTORS.
      - Galilean.
      - Opera Glass.
      - Astronomical
      - Terrestrial.
  - **MAGIC LANTERN.**
  - **STEREOSCOPE.**
  - **POLARIZATION**
    - BY ABSORPTION.
    - BY REFLECTION.
    - BY DOUBLE REFRACTION.
    - POLARISCOPES.

CONCLUSION.

ENERGY.

746. Solar Energy.—The work performed by men and other animals is due to the transformed energy of food. "This food is of vegetable origin and owes its energy to the solar rays. The energy of men and animals is, therefore, the transformed energy of the sun. Excepting the energy of the tides, the sun's rays are the source of all the forms of energy practically available. It has been estimated that the heat received by the earth from the sun each year would melt a layer of ice over the entire globe a hundred feet in thickness. This represents energy equal to one horse-power for each fifty square feet of surface."

747. Dissipation of Energy.—"It has been seen that only a fraction of the energy of heat is available for transformation into other forms of energy and that such transformation is possible only when a difference of temperature exists. Every conversion of other forms of energy into heat puts it in a form from which it can be only partially recovered. Every transfer of heat from one body to another, or from one part to another of the same body, tends to equalize temperatures and diminish the proportion of energy available for transformation. Such transfers of heat are continually taking place; and, as far as our present knowledge goes, there is a tendency toward an equality of temperature, or, in other words, a uniform molecular motion, throughout the universe. If this condition of things were reached, although the total amount of energy existing in the universe would remain unchanged, the possibility of transformation would be at an end and all activity and change would cease. This is the doctrine of the dissipation of energy to which our limited knowledge of the operations of nature leads us; but it must be remembered that our knowledge is very limited and that there may be in nature the means of restoring the differences upon which all activity depends."—*Anthony and Brackett.*

748. Varieties of Energy.—Like matter, energy is indestructible. We have already seen that energy may be visible or invisible (*i. e.*, mechanical or molecular), kinetic or potential. We have at our control at least eight varieties of energy.

(*a.*) Mechanical energy of position (visible, potential).
(*b.*) Mechanical energy of motion (visible, kinetic).
(*c.*) Latent heat (molecular, potential).
(*d.*) Sensible heat (molecular, kinetic).
(*e.*) Chemical separation (molecular or atomic; potential).
(*f.*) Electric separation (probably molecular, potential).
(*g.*) Electricity in motion (probably molecular, kinetic).
(*h.*) Radiant energy, thermal, luminous or actinic (molecular, kinetic).

749. Conservation of Energy.—The doctrine that, considering the universe as a whole, the *sum* of all these forces is a constant quantity, is known as the *Conservation of Energy.*

$$a + b + c + d + e + f + g + h = \text{a constant quantity.}$$

This does not mean that the value of a is invariable; we have seen it changed to other varieties as b or d. We have seen heat changed to electricity and *vice versa,* and either or both changed to mechanical energy. It does not mean that the sum of these eight variable quantities in the earth is constant, for we have seen that energy may pass from sun to earth, from star to star. But it does mean that the sum of all these energies in all the worlds that constitute the universe is a quantity fixed, invariable.

750. Correlation of Energy.—The expression *Correlation of Energy* refers to the convertibility of one form of energy into another. Our ideas ought, by this time, to be clear in regard to this convertibility. One important feature remains to be noticed. Radiant energy can be converted into other forms, or other forms into radiant energy only through the intermediate state of absorbed heat.

751. A Prose Poem.—"A river, in descending from an elevation of 7720 feet, generates an amount of heat competent to augment its own temperature 10° F., and this amount of heat was abstracted from the sun, in order to lift the matter of the river to the elevation from which it falls. As long as the river continues on the heights, whether in the solid form as a glacier, or in the liquid form as a lake, the heat expended by the sun in lifting it has disappeared from the universe. It has been consumed in the act of lifting. But, at the moment that the river starts upon its downward course, and encounters the resistance of its bed, the heat expended in its elevation begins to be restored. The mental eye, indeed, can follow the emission from its source through the ether, as vibratory motion, to the ocean, where it ceases to be vibration, and takes the potential form among the molecules of aqueous vapor; to the mountain-top, where the heat absorbed in vaporization is given out in condensation, while that expended by the sun in *lifting* the water to its present elevation is still unrestored. This we find paid back to the last unit by the friction along the river's bed; at the bottom of the cascade, where the plunge of the torrent is suddenly arrested; in the warmth of the machinery turned by the river; in the spark from the millstone; beneath the crusher of the miner; in the Alpine saw-mill; in the milk-churn of the chalet; in the supports of the cradle in which the mountaineer, by water-power, rocks his baby to sleep. All the forms of mechanical motion here indicated are simply the parcelling out of an amount of calorific motion derived originally from the sun; and, at each point at which the mechanical motion is destroyed or diminished, it is the sun's heat which is restored."—*Tyndall.*

Recapitulation.

ENERGY.
- **VISIBLE OR MECHANICAL.**
  - Of Position, Potential. e. g., *Hanging Apple, Head of Water.*
  - Of Motion, Kinetic. e. g., *Falling Apple, Flowing Water.*
- **SOURCE.**
- **DISSIPATION.**
- **INVISIBLE OR MOLECULAR.**
  - **HEAT.. ....**
    - Of Position, Potential. e. g., *Latent Heat.*
    - Of Motion, Kinetic. e. g., *Sensible Heat.*
  - **LIGHT..........**
    - Of Motion, or Kinetic.
  - **ELECTRICITY...**
    - Of Position, Potential. e. g., *Charged Leyden jar, Battery with circuit broken.*
    - Of Motion, Kinetic. e. g., *Leyden jar discharging: Battery with circuit closed.*

GENERAL REVIEW.

1. (*a.*) Define science, matter, mass, molecule and atom. (*b.*) How do physical and chemical changes differ? (*c.*) Define physics.

2. (*a.*) What are chemical and physical properties of matter? (*b.*) Define and illustrate two universal and one characteristic properties of matter.

3. (*a.*) Define meter, liter and gram. (*b.*) What is a solid, a liquid, and a gas? (*c.*) Define dynamics and force.

4. (*a.*) Name and define three units of force. (*b.*) Give Newton's Laws of Motion. (*c.*) Give the law of reflected motion.

5. (*a.*) Explain the parallelogram of forces, and (*b.*) the polygon of forces.

6. (*a.*) Define gravitation and give its laws. (*b.*) Give the law of weight. (*c.*) What is the centre of gravity, and how may it be found?

7. (*a.*) Describe Attwood's machine. (*b.*) Give the rules and formulas for falling bodies. (*c.*) How far will a body fall in three seconds?

8. (*a.*) What is a pendulum? (*b.*) Give the laws of the pendulum. (*c.*) How long must a pendulum be to vibrate 10 times a minute?

9. (*a.*) Define energy, foot-pound, dyne, erg, and horse-power. (*b.*) Deduce the formula for measuring kinetic energy when weight and velocity are given.

10. (*a.*) Define each of the six traditional simple machines. (*b.*) Give the law for each. (*c.*) What is the office of a machine? (*d.*) Discuss the subject of friction.

11. (*a.*) Give Pascal's law, and the rule for determining lateral liquid pressure. (*b.*) Describe the hydrostatic press, and state the general principle upon which its action depends.

12. (*a.*) State Archimedes' principle. (*b.*) What is specific gravity? (*c.*) Explain the determination of the sp. gr. of a solid lighter than water. (*d.*) Explain the use of the specific gravity bulb. (*e.*) Describe Nicholson's hydrometer and explain its use.

13. (*a.*) A 1000 gr. bottle having in it 928 grs. of water, has the remaining space filled with metallic sand and then weighs 1126.75. What is the sp. gr. of the sand? (*b.*) Through which of the three kinds of levers can the greatest power be gained? (*c.*) Through which can none be gained? (*d.*) Why do we use it? (*c.*) Give an example.

14. A ball projected vertically upward, returns in 15 seconds to the place of projection. How far did it ascend?

15. (*a.*) A floating solid displaces how much liquid? (*b.*) An immersed solid displaces how much liquid? (*c.*) A floating solid loses how much weight? (*d.*) An immersed solid loses how much weight?

16. What is the energy of a rifle-ball weighing 32 grams, having a velocity of 213 meters per second, and striking in the centre of a pendulum of wood weighing 23 kilograms?

17. (*a.*) What is meant by the increment of velocity or gravity? (*b.*) How far will a body fall in 6½ seconds? (*c.*) How far in the 9th second? (*a.*) If a freely-falling body have a velocity of 448 ft. per second, how long has it been falling?

18. (*a.*) Deduce, from the laws of falling bodies, the formula for

the velocity of spouting liquids ($v = 8.02\sqrt{h}$). (*b.*) Why must the unit of measure used with this formula be feet? (*c.*) Deduce a similar formula in which the meter is involved as the unit.

19. Name four kinds of water-wheels, and describe the most efficient of them.

20. (*a.*) Explain the action of the mercury barometer. (*b.*) Give Mariotte's law. (*c.*) Describe the piston of Sprengel's air-pump. (*d.*) Describe the ordinary air-pump. (*e.*) Explain the action of the siphon.

21. (*a.*) How would you illustrate the law of magnetic attraction and repulsion? (*b.*) Give the theory of magnetic fluids. (*c.*) What do you think of its accuracy and value? (*d.*) Explain magnetic induction.

22. If the capacity of the barrel of an air-pump be $\frac{1}{4}$ that of the receiver, how much air would remain in the receiver at the end of the fourth stroke of the piston, and what would be its tension compared with that of the external air?

23. What is the pressure on the side of a reservoir 150 feet long, and filled with water to the height of twenty feet?

24. (*a.*) Why is a reservoir usually built in connection with water-works? (*b.*) Why are fire-engines provided with an air-chamber? (*c.*) Why should the nozzle be smaller than the hose?

25. (*a.*) Why can you not raise water 50 feet with a common pump? (*b.*) What change would it be necessary to make in the pump in order to raise water to that height? (*c.*) Illustrate by a diagram.

26. (*a.*) Give the law of electrical attraction and repulsion, and illustrate by pith-ball electroscope. (*b.*) Define conductors and non-conductors, electrics and non-electrics. (*c.*) Illustrate by an example of each.

27. (*a.*) Give and illustrate each of the laws of motion. (*b.*) Explain composition and resolution of forces with illustrative figures.

28. (*a.*) Give the facts of gravity and the law of weight. (*b.*) If a body weigh 120 lbs. 2500 miles below the surface of the earth, at what distance above the surface will it weigh 80 lbs.?

29. Explain and illustrate electric induction fully.

30. (*a.*) Explain the construction and action of the electrophorus. What kind of electricity is discharged from it? (*b.*) Describe the Leyden jar and explain its action. (*c.*) Explain the action of the plate electric machine. (*d.*) In what way do lightning-rods protect buildings?

31. (*a.*) Discuss carefully the resistance of a Galvanic cell. (*b.*) Describe the Voltaic arc.

32. (*a.*) State the difference between a magnet and an electro-magnet. (*b.*) Give the principles on which the telegraph operates. (*c.*) What is meant by an "electro-negative substance?"

33. (*a.*) Describe Ruhmkorff's coil, and (*b.*) explain its action.

34. Describe the thermo-electric pile, and explain its use.

35. (*a.*) Give Prof. Tyndall's illustration of the propagation of sound. (*b.*) What is the velocity of sound in air? (*c.*) How is it affected by temperature?

36. (*a.*) Explain the difference between noise and music. (*b.*) Name the three elements of a musical sound, and state the physical cause of each.

37. (*a.*) Describe and explain the telephone. (*b.*) The phonograph.

38. (*a.*) Explain interference of sound. (*b.*) Give the laws of vibration of musical strings. (*c.*) Give the relative numbers of vibration for the tones of the major diatonic scale.

39. (*a.*) If 18 seconds intervene between the flash and report of a gun, what is its distance, temperature being 82° F.? (*b.*) If a musical sound be due to 144 vibrations per second, how many vibrations correspond to its 3d, 5th, and octave?

40. The bottom of a tank is 100 centimeters on one side, and a meter on the adjoining side. The tank has a depth of 50 centimeters of water. (*a.*) What is the pressure on the bottom? (*b.*) On either one of the vertical sides?

41. (*a.*) What is a horse-power? (*b.*) How many horse-powers are there in a machine that will raise 8250 lbs. 176 ft. in 4 minutes? (*c.*) State the modes of diminishing friction.

42. What will be the kinetic energy of a 25-pound ball that has fallen a mile? (Reject small remainders.)

43. Two bodies are attracting a third with forces as 441 to 576, the first, weighing 25 lbs., at a distance from the third of 20 feet, and the second at a distance of 30 feet; what is the weight of the second?

44. How far will a body fall in the first second on Saturn, the density of Saturn being .12 that of the earth, and its diameter being 72000 miles?

45. (*a.*) What is temperature? (*b.*) Discuss the expansion of water by heat. (*c.*) What is the rate of gaseous expansion by heat?

46. (*a.*) What is the difference between evaporation and boiling? (*b.*) What is the boiling point? (*c.*) What is distillation, and how is it performed?

47. (*a.*) Define latent, sensible and specific heat. (*b.*) What is the latent heat of water and of steam?

48. (*a.*) Explain the several modes of diffusing heat, showing how they differ. (*b.*) State and explain the relation between the absorbing and radiating powers of any given substance.

49. (*a.*) What is thermodynamics? (*b.*) State the first law of thermodynamics. (*c.*) What is the mechanical equivalent of heat in kilogrammeters? (*d.*) What does your answer mean?

50. (*a.*) Draw a figure showing the position of the parts of the cylinder and steam-chest when the piston is going up.

51. (*a.*) To what temperature would a cannon-ball weighing 150 lbs. and moving 1920 feet a second, raise 2000 lbs. of water from 32° F., if its motion were suddenly converted into heat? (*b.*) Explain the origin and propagation of sound waves.

52. (*a.*) Express a temperature of 50° F. in degrees centigrade. (*b.*) Name and describe the essential parts of a steam-engine in their proper order. (*c.*) Point out the changes in form of energy from the furnace fire, through a high-pressure engine to the heated axles set in motion thereby.

53. The mechanical equivalent of heat being 1390 foot-grams, the foot being equal to 30.48 *cm.*, and the increment of velocity on the earth being 980 *cm.*, find the mechanical equivalent in ergs.

Ans. 41519856.

54. (*a.*) What is the difference between waves of sound and waves of light? (*b.*) What is the difference between an athermanous and an opaque substance? (*c.*) What determines the apparent size of a visible object?

55. (*a.*) If the gun-cotton mentioned in § 555 (*a.*) be rubbed with a little lamp-black, will it be ignited with more or less difficulty? Why? (*b.*) What is reflection of light? (*c.*) How does it differ from refraction of light?

56. (*a.*) How could you show that light is invisible unless it enters the eye? (*b.*) What determines the apparent position of an object? (*c.*) What is the distinction between real and virtual images?

57. (*a.*) Describe and illustrate a construction for conjugate foci in the case of a concave mirror. (*b.*) In the case of a convex lens. (*c.*) What is meant by the index of refraction? (*d.*) Give the laws for refraction of light.

58. (*a.*) Explain total internal reflection. (*b.*) What is meant by dispersion of light? (*c.*) What is pure spectrum and how may it be produced? (*d.*) What are Fraunhofer's Lines and what do they indicate? (*e.*) Name the prismatic colors in order.

59. (*a.*) Why does a certain piece of glass look red when it is held between a lamp and the eye? (*b.*) Why does it look red when the lamp is between the glass and the eye? (*c.*) Explain the succession of colors in the rainbow. (*d.*) What three classes of rays in a sunbeam?

60. (*a.*) Describe the human eye as an optical instrument. (*b.*) The opera-glass. (*c.*) The terrestrial telescope. (*d.*) The stereoscope.

61. (*a.*) Explain polarization of light by absorption. (*b.*) By reflection.

62. (*a.*) Explain the action of the siphon. (*b.*) Find the volume of a balloon filled with hydrogen that has a lifting power of 440 lbs. (sp. gr. of air = 14.42. One liter of hydrogen weighs .0896 *g.*)

63. (*a.*) The barrel of an air-pump is $\frac{1}{4}$ that of the receiver; find the tension of the air in the receiver after 8 strokes of the piston, calling the normal pressure 15 lbs. and disregarding the volume of the connecting pipes. (*b.*) A stone let fall from the top of a cliff was seen to strike the bottom in $6\frac{1}{2}$ seconds; how high was the cliff?

64. (*a.*) A ship passing from the sea into a river, discharges 44800 lbs. of cargo, and is found to sink in the river to the same mark as in the sea. The sp. gr. of sea-water being 1.028, find the weight of the ship and cargo. (*b.*) A body weighing 12 lbs. (sp. gr. = $\frac{1}{5}$,) is fastened to the bottom of a vessel by a cord. Water being poured in until the body is covered, find the tension of the cord.

65. (*a.*) If the intensity of gravity at the moon be $\frac{1}{51}$ of that at the earth, find the length of a seconds pendulum at the moon, the length of one at the earth being 39.1 inches. (*b.*) Find the maximum weight that can be supported by a hydraulic elevator connected with a reservoir, the area of the piston being 24 sq. in. and the reservoir being 170 ft. above the cylinder. (*c.*) The difference between the fundamental tones of two organ-pipes of the same length, one of which is closed at the top, is an octave. Explain why.

66. If the force of gravity be taken as 980 dynes, and the mechanical equivalent of heat be 424 grammeters, what will be the value of a lesser calorie in ergs? *Ans.* 41,552,000 ergs.

APPENDIX

APPENDIX A.

Mathematical Formulas.

$\pi = 3.14159$.

Area of a circle $= \pi R^2$.

Circumference of circle $= \pi D$.

Surface of a sphere $= 4 \pi R^2 = \pi D^2$.

Volume of a sphere $\frac{4}{3} \pi R^3 = \frac{1}{6} \pi D^3$.

APPENDIX B.

Soldering.—The teacher or pupil will often find it very convenient to be able to solder together two pieces of metal. The process here described is very simple and will answer in most cases. A bit of soft solder, the size of a hazlenut, may be had gratis of any good natured tinsmith or plumber. Cut this into bits the size of a grain of wheat and keep on hand. Dissolve a teaspoonful of zinc chloride (muriate of zinc) in water and bottle it. It may be labelled "soldering fluid." If you have not a spirit-lamp obtain one, or *make one*. A small bottle (such as those in which school-inks are commonly sold) will answer your purpose. Get a *loosely* fitting cork and through it pass a metal tube about an inch long and the size of an ordinary lead pencil. Through this tube, pass a bit of candle wicking. Fill the bottle with alcohol, insert the cork, with tube and wick, and in a few minutes the lamp is ready. Having now the necessary materials you are ready for work. For example, suppose that you are to solder a bit of wire to a piece of tinned ware. If the wire be rusty, scrape or file it clean at the place of joining. By pincers or in any convenient way hold the wire and tin together. Put a few drops of "soldering fluid" on the joint, hold the tin in the flame so that the wire shall be on the upper side, place a bit of solder on the joint and hold in position until the solder melts. Remove from the flame holding the tin and wire together until the solder has cooled. The work is done. If you have a "soldering-iron," you can do a wider range of work, as many pieces of work cannot be held in the lamp flame

In soldering electric wires, do not use the "soldering fluid" above mentioned. Twist the wires together, heat the joint in the lamp flame, dip it into powdered rosin and then into coarse filings of solder, and hold it in the flame again until the adhering solder melts and "runs."

APPENDIX C.

A copy of the lecture of Prof. Crookes on "Radiant Matter" (§ 59 *b.*) may be obtained of JAMES W. QUEEN & Co., Philadelphia, for 25 cents. Teacher and pupils should secure one or more copies. The theory and experiments are alike beautiful, interesting and instructive. In concluding the lecture, Prof. Crookes said:

"In studying this Fourth State of Matter, we seem at last to have within our grasp and obedient to our control the little indivisible particles which, with good warrant, are supposed to constitute the physical basis of the universe. We have seen that, in some of its properties, Radiant Matter is as material as this table, whilst in other properties it almost assumes the character of Radiant Energy. We have actually touched the border land where Matter and Force seem to merge into one another, the shadowy realm between Known and Unknown."

APPENDIX D.

Prince Rupert Drops.—A neat illustration of the transmission of pressure by liquids (§ 216), may be given by filling a small bottle with water, holding a Prince Rupert drop in its mouth, and breaking off the tapering end. The whole "drop" will be instantly shattered and the force of the concussion transmitted in every direction to the bottle which will be thus broken. These "drops" are not expensive; they may be obtained from James W. Queen & Co., 924 Chestnut street, Philadelphia.

APPENDIX E.

Difference between Theory and Practice.—The results mentioned in § 256 are never fully attained in practice. Only the particles near the centre of the jet attain the theoretical velocity. Further than this, if we carefully examine the stream we shall notice that at a little distance from the orifice the stream is not more than two-thirds or three-fourths the size of the orifice. This is due to the fact that the liquid particles come from all sides of the opening and thus flow in different directions, forming *cross currents*, which may be seen if there are solid particles floating in the water. These cross currents impede the free flow and diminish the volume of liquid discharged. Short cylindrical or funnel-shaped tubes increase the actual flow. In a cylindrical tube, this narrowing of the jet could not take place without forming a vacuum around the narrow neck (called the *vena contracta*). The pressure of the atmosphere, tending to prevent this formation of such a vacuum, increases the velocity and the volume of the discharge. The funnel-shaped tube prevents the formation of *cross currents* by leading the liquid more gradually to the point of exit.

APPENDIX F.

Barker's Mill.—A working model of this apparatus (§ 264) may be easily made by any wide-awake pupil. Select a long, sound lamp-chimney and a fine-grained cork that snugly fits the lower end. Take a piece of glass tubing, the size of a lead pencil, heat it intensely in an alcohol or gas flame until you melt off a piece a little shorter than the lamp chimney. By reheating the end thus closed by fusion, you may give it a neat, rounded finish. Prepare four pieces of glass tubing, each 12 *cm.* long. These pieces would better be made of tubing smaller than that just used. To cut the tube to the desired length, scratch the glass at the proper point with a triangular file, hold the tube in both hands, one hand on each side of the mark just made, knuckles uppermost and thumb-nails touching each other at a point on the tube directly opposite the file-scratch, push with the thumbs and at the same time pull with the fingers. The tube will break squarely off. Smooth the sharp edges by softening in the alcohol flame. Bend each of these four pieces at right angles, 2 *cm.* from each end, in such a way that one of the short arms may be in a horizontal plane while the other short arm of the same piece is in a vertical plane. The tubes may be easily bent when heated red-hot at the proper points in the alcohol or gas flame. See that the four pieces are bent alike. In the middle of the cork, cut a neat hole a little smaller than the tube first prepared. Near the edge of the cork, at equal distances, cut four holes a little smaller than the four pieces of bent tubing. Push the open end of the straight tube through the middle hole. From the other side of the cork, enter one end of each bent tube into one of the four holes. Place the cork with its five tubes into the end of the chimney, seeing to it that the straight tube lies along the axis of the chimney, *i. e.*, that it is parallel with the sides of the chimney. The closed end of the central tube should be near the open end of the lamp-chimney. In pushing the tubes into the cork, grasp the tube (previously dipped in soap and water) near the cork, and screw it in with a slow, rotary, onward motion. See that the bent tubes are at right-angles to each other, like those shown in Fig. 91. For a support, take a piece of stout wire, small enough to turn *easily* in the central tube, and a little longer than the chimney. Place one end in the middle of a tin pepper-box and fill the box with melted lead. This makes a firm base. File the other end of the wire to a sharp point. For a few cents, such a wire with an iron base may be had ready made at the stationer's. Pass the straight tube of the apparatus over this wire until the closed end of the tube rests upon the sharpened point. The chimney, with its four horizontal arms, is now delicately suspended, free to revolve in stable equilibrium. Place the apparatus in the middle of a tub and pour water into the open end of the chimney. *Your* wheel will work as well as Queen's. The satisfaction of seeing the machine work and knowing that you made it will amply repay the cost, leaving the instruction and added skill for clear profit.

APPENDIX G.

Weight of Air.—(See § 272.) A little thought concerning the full meaning of Archimedes' Principle will show that if a body weighs less than its own bulk of air it will rise in the air. Thus, soap-bubbles filled with hydrogen or other light gas will ascend. If the bubble be made from hot water and filled with warm air it will rise; if it be made from cold water and filled with cold air it will fall. (Explain why.) The same principle applies to balloons. *A balloon will support a weight equal to the difference between the weight of the balloon with the contained gas and the weight of the air displaced.* A liter of hydrogen weighs 0.0896 *g.*; a liter of coal gas, from 0.45 *g.* to 0.85 *g.*; a liter of air heated to 200° Centigrade, about 0.8 *g.* On June 5th, 1783, at Annonay, about 40 miles from Lyons, France, the Montgolfier Bros. inflated a linen globe 105 feet in diameter with heated air. When released, it rose to a great height and descended in 10 minutes at a distance of 1½ miles. This was the discovery of the balloon. During the siege of Paris in 1870, the Parisians communicated with the outer world by means of balloons about 50 feet in diameter, having a capacity of about 70,600 cu. ft. These balloons, with net and car, weighed about 1,000 pounds each and had a carrying ability of about 2,000 pounds. Balloons have been made about 100 feet in diameter, having a capacity of about half a million cubic feet. In 1861, an ascent was made to a height of seven miles.

Air in motion constitutes a wind and has energy by virtue of its weight and velocity. Winds are utilized for moving ships, for driving windmills, etc. They arise from atmospheric disturbances caused by solar heat. The energy of wind-power like that of water-power (§§ 260, 746) is, therefore, traceable to the sun as its source.

APPENDIX H.

Atmospheric Pressure.—(See § 275.) Into a bent glass tube, *ACB*, pour mercury to a height of about 20 inches, or 50 *cm.* The mercury will, of course, stand at exactly the same level, *ac*, in the two branches. If equal pressures of any kind be exerted upon the surfaces of the mercury at *a* and *c*, this level will not be disturbed, while any difference of pressure would be promptly shown by the movement of the mercury and a consequent difference in the heights of the two mercury columns. The atmosphere presses upon both mercurial surfaces, at *a* and *c*, but it presses upon them equally and, therefore, does not change the common level. Into the arm, *A*, push an air-tight piston, *p*, which has a valve opening upward but not downward. As this piston is pushed downward, the air in *A* escapes through this valve and *p* finally rests upon the surface of the mercury at *a*. When the piston, *p*, is subsequently lifted to *A*, the atmospheric pressure is wholly removed from the surface of the mercury in that arm of the tube, while it acts with unchanged intensity upon the surface at *c*. The consequence is that the mercury follows the piston until there is a difference of about 760 *mm.* or 30 inches between the levels of the mercury in the two arms of the tube. If the tube have a sectional area of one square inch, the mercury thus supported would weigh about 15 pounds, and would exactly equal the weight of an air column of the same sectional area, reaching from the apparatus to the upper surface of the atmosphere.

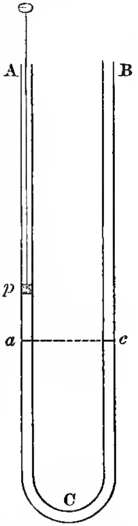


FIG. 399.

APPENDIX I.

Copper Wire.—Copper wire is usually designated by its gauge. Unfortunately there are several gauges in common use, of which the most important two are the English or Birmingham wire gauge (*B. W. G.*) and the American or Brown and Sharpe (*B. & S.*) gauge. For corresponding numbers, the *B. W. G.* is a little larger than the *B. & S.* The following table of some of the more common sizes will be convenient for reference:

AMERICAN WIRE GAUGE (B & S.).

No.	Diameter in Mils.	Diameter in Millim.	Circular Mils.	Ohms per 1000 ft.	No.	Diameter in Mils.	Diameter in Millim.	Circular Mils.	Ohms per 1000 ft.
0000	460.00	11.684	211600.0	.051	19	35.39	.899	1252.4	8.617
000	409.64	10.405	167805.0	.064	20	81.96	.812	1021.5	10.566
00	364.80	9.266	133079.4	.081	21	28.46	.723	810.1	13.323
0	324.95	8.254	105592.5	.102	22	25.35	.644	642.7	16.799
1	289.30	7.348	83694.2	.129	23	22.57	.573	509.5	21.185
2	257.63	6.544	66373.0	.163	24	20.10	.511	404 0	26.713
3	229.42	5.827	52634.0	.205	25	17.90	.455	320.4	33.684
4	204.31	5.189	41742.0	.259	26	15.94	.405	254.0	42.477
5	181.94	4.621	33102.0	.326	27	14.19	.361	201.5	53.553
6	162.02	4.115	26250.5	.411	28	12.64	.321	159.8	67.542
7	144.28	3.665	20816.0	.519	29	11.26	.286	126.7	85.170
8	128.49	3.264	16509.0	.654	30	10.03	.255	100.5	107.391
9	114.43	2.907	13094.0	.824	31	8.93	.227	79.7	135.402
10	101.89	2.588	10381.0	1.040	32	7.95	.202	63.2	170.765
11	90.74	2.305	8234.0	1.311	33	7.08	.180	50.1	215.312
12	80.81	2.053	6529.9	1.653	34	6.30	.160	39.7	271.583
13	71.96	1.828	5178.4	2.084	35	5.61	.143	31.5	342.443
14	64.01	1.628	4106.8	2.628	36	5.00	.127	25.0	431.712
15	57.07	1.450	3256.7	3.314	37	4.45	.113	19.8	544.287
16	50.82	1.291	2582.9	4.179	38	3.96	.101	15.7	686.511
17	45.26	1.150	2048.2	5.269	39	3.53	.090	12.5	865.046
18	40.30	1.024	1624.3	6.645	40	3.14	.080	9.9	1091.865

Note.—The second column gives the diameters in thousandths of an inch; the third column, in millimeters. The fourth column gives the equivalent number of wires each one mil in diameter. The numbers therein given are the squares of the diameters in mils. By multiplying the numbers in the fifth column by 5.28, the resistances per mile may be found. The resistance for any other metal than copper may be found by multiplying the resistance given in the table by the ratio between the specific resistance of copper and the specific resistance of the given metal. (See table of specific resistances in Appendix K [2]). The resistances given in the table are for *pure* copper wire at a temperature of 75° F. or 24° C. Ordinary commercial copper wire has a conductivity of about 95 or 96 *per cent.* that of pure copper. Consequently, the resistances of such wires will be about 5 *per cent.* greater than those given in the table.

STUBS' OR BIRMINGHAM WIRE GAUGE (B. W. G.).

No.	Diameter in Mils.	Diameter in Millim.	No.	Diameter in Mils.	Diameter in Millim.	No.	Diameter in Mils.	Diameter in Millim.
0000	454	11.53	8	165	4 19	18	49	1.24
00	380	9.65	10	134	3.40	20	35	0.89
1	300	7.62	12	109	2.77	24	22	0.55
4	238	6.04	14	83	2 11	30	12	0.31
6	203	5.16	16	65	1.65	36	4	0.10

The catalogue of electrical wires (furnished gratis by Holmes, Booth & Haydens, 22 Murray street, New York City, or by The Electrical Supply Co., 17 Dey street), contains many valuable tables and other information.

APPENDIX J.

The Leyden Jar.—The following is extracted (as much other information in this volume has been) from Silvanus Thompson's "Elementary Lessons in Electricity and Magnetism":

The existence of a residual charge (§ 356) can be explained either on the supposition that the dielectric is composed of heterogeneous particles which have unequal conducting powers or on the hypothesis that the molecules are actually subjected to a strain from which, especially if the stress be long continued, they do not recover all at once. There is an analogy between this phenomenon and that of the "elastic recovery" of solid bodies after being subjected to a bending or a twisting strain. A fibre of glass, for example, twisted by a certain force, flies back when released to *almost* its original position, a slight sub-permanent set remains from which, however, it slowly recovers itself, the rate of its recovery depending on the amount and duration of the original twisting strain. It is possible to superpose several residual charges, even charges of opposite signs, which apparently "soak out" as the strained material gradually recovers itself.

As to the precise nature of the molecular or mechanical operations in the dielectric when thus subjected to the stress of electrostatic induction, nothing is known. One pregnant experiment of Faraday is of great importance, by showing that induction is, as he expressed it, "an action of contiguous particles." In a glass trough, *T* (Fig. 400), is placed some oil of turpentine, in which are put some fibres of dry silk cut into small bits. Two wires pass into the liquid, one of which is joined to earth, the other being put into connection with *C*, the prime conductor of an electrical machine. The bits of silk come from all parts of the liquid and form a chain of particles from wire to wire, *p* to *p'*. On touching them with a glass rod they resist being pushed aside, though they at once disperse if the supply of electricity is stopped. Faraday regarded this as typical of the internal actions in every case of induction across a dielectric, the particles of which he supposed to be "polarized," that is, to be turned into definite positions, each particle having a positive and a negative end. The student will perceive an obvious analogy, therefore, between the condition of the particles of

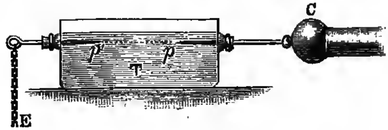


FIG. 400.

a dielectric across which electrostatic induction is taking place, and the molecules of a piece of iron or steel when subjected to magnetic induction.

Siemens has shown that the glass of a Leyden jar is sensibly warmed after being several times rapidly charged and discharged. This obviously implies that molecular movement accompanies the changes of dielectric stress.

The internal volume of a Leyden jar is increased when it is charged, as though the attraction between the two charged surfaces compressed the glass and caused it to expand laterally.

APPENDIX K.

(1.) **Electrical Resistance.**—The idea implied in resistance is that of a force opposing the E. M. F. which maintains the current. It is analogous to friction in mechanics. The resistances of a circuit are of two kinds, viz., the resistances of the conductors themselves and the resistances due to imperfect contact. The latter kind is affected by pressure, which brings the surfaces into more intimate contact. The contact resistance of two wire conductors may vary from infinity to the small fraction of an ohm. Hence, great care should be exercised in splicing two such wires, by seeing that the contact surfaces are clean and that the wires are tightly twisted together. In many cases, it is desirable to solder the spliced wires.

(2.) **Specific Resistance.**—The specific resistance of a substance is best stated as the resistance in absolute units (*i. e.*, in billionths of an ohm) of a cubic centimeter of the substance.

TABLE OF SPECIFIC RESISTANCES AND RELATIVE CONDUCTIVITIES.

SUBSTANCE.	SPECIFIC RESISTANCE.	RELATIVE CONDUCTIVITY.
Metals.		
Silver,	1,609	100
Copper,	1,642	98
Gold,	2,154	74
Platinum,	8,930	18
Iron (soft),	9,827	16
Lead,	19,847	8
German Silver,	21,170	7·5
Mercury (liquid),	96,146	1·6
Selenium (annealed),	6×10^{13}	$\frac{1}{40\,000\,000\,000}$
Liquids.		
Pure Water at 22° C,	$7·18 \times 10^{10}$	Less than *one millionth* part.
Dilute Sulphuric Acid ($\frac{1}{12}$ acid),	$·332 \times 10^{10}$	
Dilute H_2SO_4 ($\frac{1}{3}$ acid)	$·126 \times 10^{10}$	
Insulators.		
Glass (at 200° C),	$2·27 \times 10^{16}$	Less than *one millionth* of a *millionth* part.
Gutta-percha (at 20° C)	$3·5 \times 10^{23}$	

If the poles of 100 Daniell cells be connected with tin-foil sheets 1 *m.* square pasted on opposite faces of a plate of gutta-percha 1 *cm.* thick, less than 10 coulombs would pass through this circuit of very high resistance in a whole century.

Those substances that possess a high conducting power for electricity are the best conductors of heat (§ 604 [*b.*]). Liquids are worse conductors than the metals and gases are perfect non-conductors, except when so rarefied as to admit of discharge by convection through them.

(3.) **Effects of Heat on Resistance.**—The resistance of a conductor is constant as long as the molecular condition of the conductor is unchanged. But it is changed by heat, strain, tempering, magnetization and, in some cases, by light. The resistance of metals increases considerably as the temperature is raised. On the other hand, the resistance of carbon appears to diminish on heating. German-silver and other alloys do not show so much change, hence they are used in making standard resistance-coils. Liquids that conduct only by being electrolyzed conduct better as the temperature rises. *Vide*, Encyclopædia Britannica, vol. viii, p. 52 (*Ninth edition*).

(4.) **Effect of Light on Resistance.**—Ordinary fused or vitreous selenium (Chemistry, § 160) is a very bad conductor; its resistance being nearly 3.8×10^{10} times as great as that of copper. When carefully annealed (by keeping for some hours at a temperature of about 220° C., just below its fusing point, and subsequently cooling slowly), it assumes a crystalline condition, in which its electric resistance is considerably reduced. In the latter condition, especially, its resistance is considerably and instantly lessened by exposure to light. Greenish-yellow rays are the most effective. Prof. Graham Bell and Mr. Sumner Tainter have devised forms of "selenium cells," in which the selenium is formed into narrow strips between the edges of broad conducting plates of brass, thus securing both a reduction of the transverse resistance and a large amount of surface-exposure to light. The resistance of such a cell in the dark was 300 ohms; when exposed to sunlight, it had a resistance of but 150 ohms. This property of selenium has been applied in the construction of the *Photophone,* an instrument which transmits sounds to a distance by means of a beam of light. The light is reflected to the distant station by a thin mirror thrown into vibrations by the voice; the beam falling, consequently, with varying intensity upon a receiver of selenium connected in circuit with a small battery and a Bell telephone. The sounds are thus reproduced by the variations of the current.

Similar properties are possessed, to a smaller degree, by *tellurium* (Chemistry, § 161).

APPENDIX L.

(1.) **The Tangent Galvanometer.**—It is not possible to make a galvanometer in which the strength of current shall be proportional to the *angle* of deflection through its whole range. But a simple galvanometer may be made in which the strength of the current shall be proportional to the *tangent* of the angle of deflection. The tangent galvanometer, one form of which is shown in Fig. 401, is such an instrument. A horizontal needle (§ 439*a*) not more than an inch long is delicately suspended at the centre of a stout copper wire hoop about fifteen inches in diameter. The single coil or hoop being placed in the magnetic meridian, *a current flowing through the coil will deflect the needle through such an angle that the tangent of the angle of deflection is proportional to the strength of the current.* For example, suppose that a certain battery gives a deflection of 15° and a second battery gives a deflection of 30°. The numbers of amperes are not in the ratio of 15 : 30 but in the ratio of tan 15° : tan 30°. The values of such tangents must be obtained from a Table of Natural Tangents (see below), from which it will be found that the strengths of the currents are in the ratio of

$$0.268 : 0.577, \text{ or about } 10 : 22.$$

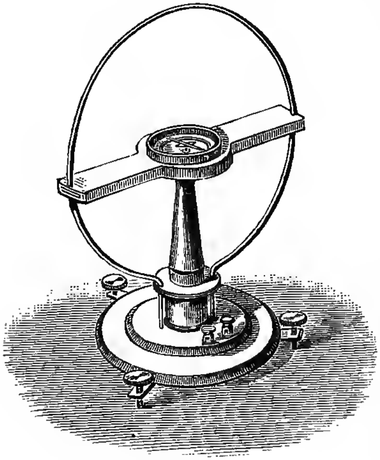


FIG. 401.

If a known current, C, gives a deflection of m degrees and an unknown current, c, gives a deflection of n degrees, the value of c may be found (with the help of the table below) from the proportion

$$C : c \ :: \ \tan m : \tan n.$$

A delicate, stiff pointer or index of aluminum (Chemistry, § 346) is usually fastened to the short, stout needle of the tangent galvanometer. But, at the best, this instrument is not very sensitive.

TABLE OF NATURAL TANGENTS.

ARC.	TANGENT.	ARC.	TANGENT.	ARC.	TANGENT.	ARC.	TANGENT.
1°	.017	24°	.445	47°	1.07	70°	2.75
2	.035	25	.466	48	1.11	71	2.90
3	.052	26	.488	49	1.15	72	3.08
4	.070	27	.510	50	1.19	73	3.27
5	.087	28	.532	51	1.23	74	3.49
6	.105	29	.554	52	1.28	75	3.73
7	.123	30	.577	53	1.33	76	4.01
8	.141	31	.601	54	1.38	77	4.33
9	.158	32	.625	55	1.43	78	4.70
10	.176	33	.649	56	1.48	79	5.14
11	.194	34	.675	57	1.54	80	5.67
12	.213	35	.700	58	1.60	81	6.31
13	.231	36	.727	59	1.66	82	7.12
14	.249	37	.754	60	1.73	83	8.14
15	.268	38	.781	61	1.80	84	9.51
16	.287	39	.810	62	1.88	85	11.43
17	.306	40	.839	63	1.96	86	14.30
18	.325	41	.869	64	2.05	87	19.08
19	.344	42	.900	66	2.14	88	28.64
20	.364	43	.933	66	2.25	89	57.29
21	.384	44	.966	67	2.36	90	Infinite.
22	.404	45	1.000	68	2.48		
23	.424	46	1.035	69	2.61		

(2.) **The Sine Galvanometer.**—Any sensitive galvanometer, the needle of which is directed by the earth's magnetism and in which the frame on which the coils are wound is capable of being turned round a central axis, may be used as a Sine Galvanometer. The coils are set parallel to the needle (*i. e.*, in the magnetic meridian). The current is then sent through the coils, deflecting the needle. The coil is then turned until it overtakes the needle which once more lies parallel to the coil. Two forces are now acting on the needle and balancing each other, *viz.*, the directive force of the earth's magnetism and the deflecting force of the current flowing through the coil. At this moment, *the strength of the current is proportional to the sine of the angle through which the coil has been turned.* The values of the sines must be obtained from a Table of Natural Sines.

TABLE OF NATURAL SINES.

ARC.	SINE.	ARC.	SINE.	ARC.	SINE.	ARC.	SINE.
0°	.000	9°	.156	50°	.766	83°	.993
1	.017	10	.174	55	.819	84	.995
2	.035	15	.259	60	.866	85	.996
3	.052	20	.342	65	.906	86	.998
4	.070	25	.423	70	.940	87	.999
5	.087	30	.500	75	.966	88	.999
6	.105	35	.574	80	.985	89	.999
7	.122	40	.643	81	.988	90	1.000
8	.139	45	.707	82	.990		

(3.) **The Mirror Galvanometer.**—In this instrument, a very light mirror of silvered glass is fastened to the needle so that a beam of light may be reflected upon a graduated scale. The slightest motion of the needle is thus magnified and made apparent. Fig. 402 shows the mirror galvanometer devised by Sir W. Thomson for signalling through submarine cables. The magnet consists of one or more pieces of steel watch spring fastened to the back of a small concave mirror which is hung by a single fibre of cocoon silk within the coil. A curved magnet, carried on a vertical support above the coil, serves to counteract the earth's magnetism and to direct the needle within the coil. A beam of light from the lamp passes through a small opening under the scale, falls upon the mirror and is reflected back upon the scale. The curved magnet above the coil enables the operator to bring the spot of reflected light to the zero mark at the middle of the scale. A current passing through the coil turns the needle and its mirror, thus shifting the spot of light to the right or left of the zero point. The apparatus is wondrously sensitive. The current produced by dipping the point of a brass pin and the point of a steel needle into a drop of salt water and closing the external circuit through this instrument sends the spot of light swinging way across the scale.

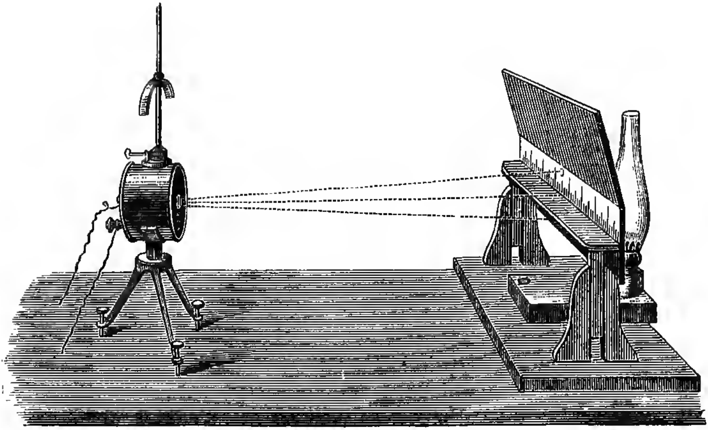


FIG. 402.

(4.) **The Differential Galvanometer.**—In this instrument, the coil is made of two separate wires wound side by side. If two equal currents are sent through these wires in opposite directions, the needle will not be deflected. If the currents are unequal, the needle will be deflected by the stronger one with a force corresponding to the difference of the strengths of the two currents. It is much used in "nil" methods of measurements. [See App. M (3).]

APPENDIX M.

Electrical Measurements.—The wonderful advance made by electrical science within the last few years is largely due to the adoption of a system of exact measurements. In September, 1881, the Paris Electrical Congress, composed of representative electricians of all countries, established a system of new (C. G. S.) electrical units which are now generslly accepted and used.

(1.) **Resistance Coils.**—Wires of standard resistance are now sold by instrument makers under the name of *Resistance Coils.* They consist of coils of german-silver (or sometimes silver-iridium alloy), wound with great care and adjusted to such a length as to have resistances of a definite number of ohms. In order to avoid self-induction and the consequent sparks at the opening or closing of the circuit, they are wound in the peculiar manner indicated in Fig. 403, each wire (covered with silk or paraffined-cotton) being doubled on itself before being coiled up. Each end of a coil is soldered to a solid brass piece, as coil 1 to *A* and *B*, coil 2 to *B* and *C*; the brass pieces being themselves fixed to a block of ebonite (forming the top of the "resistance box"), with sufficient room between them to admit of the insertion of stout, well-fitting plugs of brass. Fig. 404 shows a complete resistance-box, as fitted up for electrical testing, with the plugs in

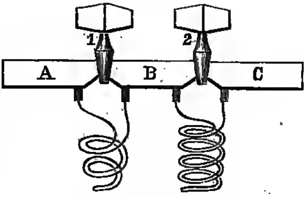


FIG. 403.

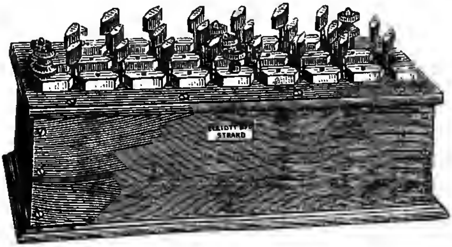


FIG. 404.

their places. So long as the plugs remain in, the current flows through the solid brass pieces and plugs without encountering any serious resistance; but when any plug is removed, the current can pass from the one brass piece to the other only by traversing the coil thus thrown into circuit. The series of coils chosen is usually of the following numbers of ohms' resistance—1, 2, 2, 5; 10, 20, 20, 50; 100, 200, 200, 500; . . . . up to 10,000 ohms. By pulling out one plug any one of these can be thrown into the circuit and any desired whole number, up to 20,000, can be made up by pulling out more plugs; thus a resistance of 263 ohms will be made up as 200 + 50 + 10 + 2 + 1.

(2.) **Measuring External Resistances.**—(*a.*) Suppose that we have a standard battery of a few Daniell's cells, joined up in circuit with R, a wire of unknown resistance, and with a galvanometer, that indicates a current of a certain strength, as shown in Fig. 405. If we remove the wire, R, and, in its place in the circuit, substitute wires *whose resistances we know*, we may, by trying, find one which, when interposed in the path of the current, gives the same deflection of the galvanometer needle. Hence, we shall know that this wire and the one we called R offer equal resistances to the current.

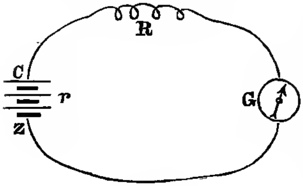


FIG. 405.

(*b.*) A rheostat is a long thin wire coiled upon a wooden cylinder, so that any desired length of the wire may be thrown into the circuit by unwinding the proper number of turns of wire off the cylinder, or by making contact at a point at any desired distance from the end of the wire. The rheostat has been superseded by the resistance coils mentioned above.

(*c.*) The method explained above may be used with any galvanometer of sufficient sensitiveness, but if a tangent galvanometer is available the process may be shortened. Suppose the tangent galvanometer and an unknown resistance, R, to be included in the circuit, as in Fig. 405, and that the current is strong enough to produce a deflection of a degrees. Substitute for R any known resistance, r, which will alter the deflection to b degrees; then (provided the other resistances of the circuit be negligibly small) it is clear that since the strengths of the currents are proportional to $\tan a$ and $\tan b$ respectively, the resistance, R, may be calculated by the inverse proportion:

$$\tan a : \tan b = r : R.$$

(*d.*) With a differential galvanometer and a set of standard resistance coils, it is easy to measure the resistance of a conductor. Let the circuit of a battery divide into two branches, so that part of the current flows through the given resistance and round one set of coils of the galvanometer, the other part of the current being made to flow through known resistances and then round the other set of coils in the opposing direction. When we have succeeded in matching the unknown resistance by one equal to it from the known resistances, the currents in the two branches will be equal and *the needle of the differential galvanometer will show no deflection.* With an accurate instrument, this method is very reliable.

Or we may vary the resistance of the second circuit until it balances the given resistance; remove the given resistance and put known resistances in its place until the galvanometer again shows no deflection. This is the better way, as it gives good results even if the two coils of the galvanometer are not exactly symmetrical. (Compare § 177.)

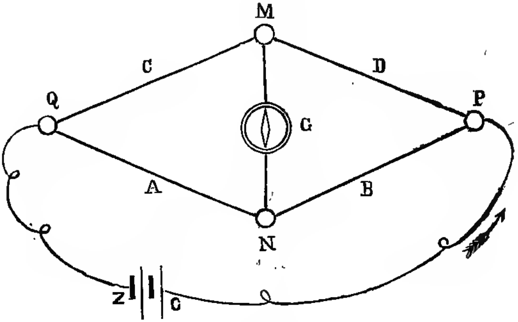


FIG. 406.

(*e.*) The best of all the ways of measuring resistances is, however, with a set of standard resistance coils and the important instrument known as Wheatstone's Bridge. This instrument is represented by the diagram shown in Fig. 406. The circuit of a constant battery is made to branch at *P* into two parts which reunite at *Q*, so that part of the current flows through the point *M*, the other through the point *N*. The four conductors, *A*, *B*, *C* and *D*, are called the *arms of the bridge.* The resistance of any three of these arms being known, that of the remaining one may be calculated. When the current that starts from the battery arrives at *P*, the potential will have fallen to a certain value. The potential of the current in the upper branch falls again to *M* and continues to fall to *Q*. The potential of the lower branch falls to *N* and continues to fall until, at *Q*, it is of the same value as that of the upper branch at the same point. If the ratio of the resistance of *C* to the resistance of *D* is the same as the ratio of the resistance of *A* to the resistance of *B*, then will *M* and *N* be at equal potentials. If a sensitive galvanometer, placed in the branch wire between *M* and *N*, shows no deflection, we may know that *M* and *N* are at equal potentials and that the resistances of the four arms "balance" by being in proportion, thus:

$$A : C = B : D.$$

For example, if the resistances, *A* and *C*, are (as indicated in Fig. 407) 10 ohms and 100 ohms respectively and the resistance of *C* is 15 ohms, the resistance of *D* will be 150 ohms.

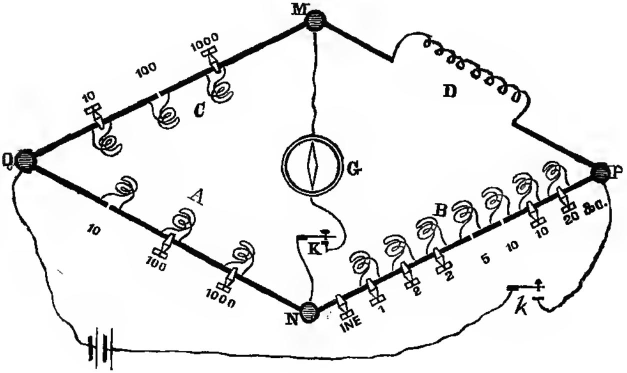


FIG. 407.

It is usual to construct Wheatstone's bridges with some resistance coils in the arms, *A* and *C*, as well as with a complete set in the arm, *B*. The advantage of this arrangement is that by adjusting *A* and *C* we determine the ratio between the resistances of *B* and *D* and can, in certain cases, measure to fractions of an ohm. Fig. 407 shows a more complete scheme, in which resistances of 10, 100 and 1,000 ohms are included in the arms, *A* and C.

For example, suppose that we have a wire, the resistance of which we know to be between 46 and 47 ohms and wish to measure the fraction of an ohm. Insert the wire at *D*. Make the resistance of *A*, 100 ohms and that of *C*, 10 ohms. In this case, *D* must be balanced by a resistance in *B*, 10 times as great as that of *D*. If, on trial, this is found to be 464 ohms, we know that the resistance of *D* is (464 × 10 ÷ 100 =) 46.4 ohms.

In practice, the bridge is not made in the diamond shape of the diagrams. The resistance box shown in Fig. 404 is a complete bridge, the appropriate connections being made by screws at various points. In using the bridge, the battery circuit should always be made by depressing the key, *k*, before *K*, the key of the galvanometer branch is depressed. This avoids the sudden "throw" of the galvanometer needle, in consequence of the self-induction, when the circuit is closed (§ 458).

Vide, Encyclopædia Britannica (9th edition), vol. viii, pp. 43 to 46.

(3.) **Measuring Internal Resistance.**—The best way of determining the internal resistance of a voltaic cell is to join two similar cells in opposition to one another, so that they send no current of their own. Then measure their united resistance (as if it were the resistance of a wire) as just described. The resistance of one cell will be half that of the two.

(4.) **Measuring Electromotive Forces.**—The usual method of measuring E. M. F. is by comparison with the E. M. F. of a Daniell cell (= 1.079 volts).

(*a*.) Represent the E. M. F. of the standard cell or battery by *E* and that of the given cell or battery by *X*. Join cell *X* with the galvanometer and note the number of degrees of deflection that it produces through the resistances of the circuit. Represent this deflection by *a*. Then add enough resistance, *R*, to bring the deflection down to *b* degrees (*e. g.*, 10 degrees less than before). Then substitute the standard for the given battery in the circuit and adjust the resistances of the circuit until the galvanometer shows a deflection of *a* degrees, as at first. Add enough resistance, *r*, to bring the deflection down to *b* degrees as before. *E*, *R* and *r* being known, *X* may be found from the proportion,

$$r : R :: E : X,$$

because the resistances that will produce an equal reduction of current will be proportional to the electromotive forces.

(*b*.) If the poles of a standard battery are joined by a long, thin wire, the potential will fall uniformly from the + to the − pole. Hence, by making contacts at one pole and at a point any desired distance along the wire, any desired proportional part of the whole electromotive force may be taken. This proportional part may be balanced against the electromotive force of any other battery, or used to compare the difference between the electromotive forces of two different cells.

(*c.*) A galvanometer having a coil resistance of several thousand ohms (in comparison with which the internal resistance of a battery or dynamo is insignificant) may be used to measure E. M. F., for, by Ohm's law, the strength of current that such a battery or dynamo can send through it will depend only on the E. M. F. (or difference of potential) between the ends of the coil. Such a galvanometer, properly graduated, is called a *voltmeter* or a *potential galvanometer.* It may be used to determine the difference of potential between any two points of a circuit by placing the galvanometer in a shunt circuit between those two points.

(*d.*) The following method was devised by Dr. C. F. Brush for determining the difference of potential between the terminals of a standard Brush arc lamp: A battery of 48 small Daniell cells had its + electrode connected to the + terminal of the lamp (which was in the dynamo circuit) and its — electrode connected to the — terminal of the lamp, a very sensitive galvanometer being placed in the battery circuit which was thus completed through the lamp. It is evident that if the difference of potential between the ends of the battery is greater than that between the terminals of the lamp, the current will circulate in its normal direction through the battery and will be indicated by the galvanometer; but if this potential is less than that of the lamp, the current will flow through the battery but in a reverse direction and will be so indicated by the galvanometer; while, if the difference of potential is the same in both, no current will pass in either direction through the battery and *the galvanometer will show no deflection.*

The E. M. F. of the battery exceeding the difference of potential between the terminals of the lamp, cells were gradually removed until the galvanometer indicated no current or currents fluctuating from zero equally in both directions. The large number of observations made sufficiently eliminated the error due to the fact that no fraction of a single cell of the battery could be used in the experiments. This method of measuring the difference of potential between the terminals of the lamp proved to be extremely satisfactory and certain in its operation, the addition or subtraction of a single cell of battery being sufficient to deflect the galvanometer needle strongly to the right or left. By finding the average result of all the observations, it was found that the difference of potential between the terminals of the *average* lamp was equal to that of 42.46 cells of the battery, or 45.8 volts.

The resistance of the lamp being measured was found to be 4.56 ohms. Therefore, the current passing in the dynamo circuit was (45.8 ÷ 4.56 =) 10.04 amperes.

(5.) **Measuring Capacity.**—The capacity of a condenser is generally measured by comparing it with the capacity of a standard condenser. Fig. 408 represents a $\frac{1}{8}$ microfarad condenser. The two brass pieces upon the ebonite top are connected respectively with the two series of alternate sheets of tin-foil. The plug between them serves to keep the condenser discharged when not in use.

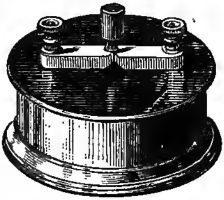


FIG. 408.

(*a.*) Charge the given condenser to a certain potential and make it share its charge with a condenser of known capacity. Measure the potential to which the charge sinks. Calculate the original capacity, which will bear the same ratio to the total capacity of the two condensers that the final potential bears to the original potential.

(*b.*) Charge the two condensers simultaneously from one pole of the same battery, interposing high resistances in each branch and adjusted so that the potential rises at an equal rate in both; then the capacities are inversely proportional to the resistances through which they are respectively being charged.

(*c.*) The following method requires no condenser: Allow the given condenser to discharge itself slowly through a wire of very high resistance. The time taken for the potential to fall to any given fraction of its original value is proportional to the resistance, to the capacity and to the logarithm of the given fraction.

(*d.*) The capacity of a condenser, like that of a simple conductor, is measured by the quantity of electricity required to produce unit rise of potential.

APPENDIX N.

Field of Force.—"A field of force is a region such that a particle constituting a part of a mutually interacting system, placed at any point in the region, will be acted on by a force and will move, if free to do so, in the direction of the force. The particle so moving would, if it had no inertia, describe what is called a line of force, the tangent to which, at any point, is the direction of the force at that point. The strength of the field at a point is measured by the force developed by unit quantity at that point and is expressible, in terms of lines of force, by the convention that each line represents a unit of force and that the force acting on unit quantity at any point varies as the number of lines of force which pass perpendicularly through unit area at that point. Each line, therefore, represents the direction of the force and the number of lines in unit area, the strength of field. An assemblage of such lines of force, considered with reference to their bounding-surface, is called a tube of force."—*Anthony and Brackett.*

APPENDIX O.

The Telephone.—(Sec § 506.) The theory that the diaphragm of the receiving telephone is made to vibrate to and fro by the varying intensity of the magnetic attraction of the iron core has lately been questioned. Many experiments go to show that the variations in the magnetic intensity of the iron core are too feeble to produce such mechanical effects. It also appears that paper and other substances may replace the iron of the diaphragm in the *receiving* telephone, without destroying the sounds, and that the diaphragm may even be removed and the sounds still produced and transmitted to the ear. These facts are believed to show that the reproduced sound is due to *movements of the molecules* of the iron core, such molecular motions being due to the electric currents from the "transmitter" (or telephone spoken to), and that the diaphragm is valuable for the purposes of strengthening the sound (§ 510) and transmitting it to the ear of the listener. The scientific paper, *Nature*, says that careful investigation leads to the conclusion that, at the sending station, the evidence of molecular action, though suggestive, is by no means conclusive, whereas, at the receiving station, the existence of molecular as well as mechanical action amounts to demonstration and is shown to be considerable in amount.

"The infinite varieties of sound are due to the subtile capacity for complex motion possessed by air particles. If we could see the dance of the air particles when music is executed, it would be a picture of mathematical exactness and infinite complication that has no analogy in anything we observe. It has always been regarded as one of the mysterious miracles of vital structure that the drum of the human ear can take up so perfectly this rapid stream of intricate motions in the air, thousands of tympanums being affected alike, while the nerves transmit the thrills to the brain, awakening the same musical sensations in the consciousness of as many persons as can be brought within hearing. The chain of effects is wonderful indeed, but the diaphragm of the telephone is as sensitive as the living tympanum to all the delicate refinements of sound. Let a word be pronounced for a person to repeat; the telephone will hear and speak it a hundred miles away in a tenth part of the time that the listener would need to utter it."

APPENDIX P.

The Phonograph.—(See § 508.) The appearance of this instrument is shown in the accompanying cut, in which *F* represents the mouthpiece; *C*, the cylinder covered with tin-foil; *E*, the axis with a thread working in *A*, one of the two supports. The mouthpiece, with its diaphragm and style, may be moved toward the cylinder or from it, by means of the supporting lever, *HG*, which turns in a horizontal plane about the pin, *I*.

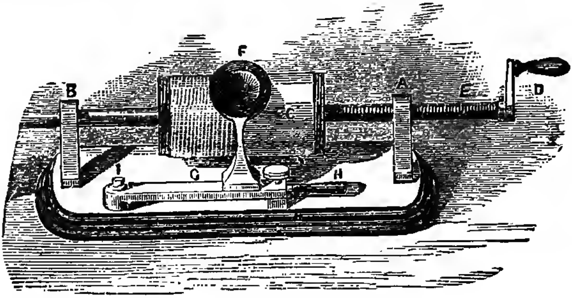


FIG. 409.

APPENDIX Q.

The Sonometer.—(See § 519.) The sonometer box may be made by any carpenter. It is about fifty-nine inches long, $4\frac{3}{4}$ inches wide and $4\frac{3}{4}$ inches deep. The ends are made of inch oak boards, the sides of $\frac{1}{2}$ inch oak boards and the top of $\frac{1}{8}$ inch pine board. The top should be glued on; no bottom is needed; the box may sit directly on the table. Three or four one-inch holes may well be bored in each side-piece. The two bridges, shown at *A* and *B* (Fig. 268), should be of very hard wood and glued to the cover just $47\frac{3}{4}$ inches (120 centimeters) apart, measured from centre to centre. The strings may be such as are used on bass-viols; they should be alike. Two similar pieces of piano-forte wire (large size) may be used. The strings may be stretched by weights as shown in the figure or by two piano string pegs turned with a wrench or a piano tuner's key. The familiar screw arrangement of the bass-viol may be used for the purpose. If piano wires are used for strings, the ends must be annealed by heating them red hot and cooling them slowly, so that they may remain fixed when wound around their fastenings. Lines should be drawn across the top of the box, exactly dividing the distance between the middle of the bridges (at which points the strings are supported) into halves, thirds and quarters. Provide a block of wood, about two inches wide, 4½ inches long and just thick enough to slip between the strings and the top of the box. (See Fig. 279.)

APPENDIX R.

Differential Thermometer.—(See § 547.) Prepare two boards, each 5 × 7 inches and an inch thick. Place them upon end parallel to each other, 7 inches apart. Connect the boards by nailing to their tops two thin strips, each an inch wide and 9 inches long. The strips will be 3 inches apart. This is our stand. For the two bulbs, use two tin oyster cans with flat sides. To the centre of one end of each, solder a tin tube, 1½ inches long and ⅜ of an inch in diameter. Take a 30-inch piece of glass tubing that will slide easily within the tin tubes. Bend it at right angles, 12 inches from each end, like the tube shown in Fig. 289. Color a little alcohol with red aniline, and pour into the bent tube enough to fill an inch or two above each bend. Over each arm of the bent tube, pass an inch of snugly-fitting rubber-tubing and slide it down about 8 inches. Pass the arms of the glass tube up through the tin tubes of the inverted cans as far as they will go. Slide the rubber-tubing upward to make air-tight joints between the glass and the tin tubes. Place the cans upon the horizontal strips of the frame already made, allowing the glass tube to hang between the boards. The level of the liquid in either arm may be marked by a thread or rubber band that may be moved up or down.

APPENDIX S.

Cut-off Engines.—With a plain sliding valve, like that described in § 637, the steam pressure is evidently the same at the end as at the beginning of the stroke of the piston. But the greatest economy of operation is attained when the steam is so used that, when the piston has reached the end of its stroke and the exhaust valve is opened, the steam pressure is but little if any above that of the atmosphere. To secure this economy, the Cut-off Engine has been devised. Here, the steam is not admitted to the cylinder during the full travel of the piston, but is cut off at an earlier or later point of the stroke, the steam already admitted expanding with decreasing pressure to the end of the stroke. The engine may be built so as to cut off at a certain fraction of the stroke, as three-fourths, obtaining the benefit of the expansion of the steam for the remaining one-fourth. This arrangement is called *a fixed cut-off.*

But in many cases, the power required is frequently varying with the nature of the work, and the point of cut-off best adapted to one load is unfitted to another. Hence, the desirability of being able to shift the point of cut-off to an earlier or later part of the stroke. Many devices have been brought forth to secure this object. If the shifting be done by hand, the arrangement is called *an adjustable cut-off;* if it be done by the governor, the arrangement is called *an automatic cut-off.*

APPENDIX T.

Telescopes.—(See §§ 731 and 732.) In estimating the efficiency of a telescope, the *illuminating* power must be considered as well as the *magnifying* power. The brilliancy of the image depends largely upon the diameter of the object-glass or reflector. It is evident that of two telescopes having equal magnifying power, the one that has the larger "aperture" will receive and transmit more luminous rays and, hence, cause the image to be better illuminated and more distinct.

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